NASA CR-54178
PWA-2315

EXPERIMENTAL CONDENSING-FLOW STABILITY STUDIES

N64-31716
(ACCESSION NUMBER)
136
(PAGES)
CR-54178
(NASA CR OR TMX OR AD NUMBER)
(THRU)
1
(CODE)
(CATEGORY)
FACILITY FORM 602

by

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prepared for
National Aeronautics and Space Administration
Contract NAS3-2335

Pratt & Whitney Aircraft DIVISION OF UNITED AIRCRAFT CORPORATION

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NASA CR-54178
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TOPICAL REPORT

EXPERIMENTAL CONDENSING-FLOW STABILITY STUDIES

prepared for
National Aeronautics and Space Administration

April 15, 1964

Contract NAS3-2335

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FOREWORD

This report was prepared by the Pratt & Whitney Aircraft Division of United Aircraft Corporation, East Hartford, Connecticut, to describe in part the work conducted from June 1 to December 1, 1963 in fulfillment of Task III, Item A of Contract NAS3-2335, Amendment 1, Experimental Investigation of Transients in Space Rankine Powerplants. It summarizes the experimental aspects of Task III, Item A, and deals with flow stability inside condensing tubes.

Task III, Item A consisted of an analytical and experimental study of convectively-cooled indirect condensers for Rankine-cycle space powerplants. The analytical part of the task was directed towards identifying the most promising condenser concept based on considerations of heat transfer, fluid mechanics, structural integrity, fabrication and sealing, and systems integration. The results of the analytical study are contained in Report PWA-2320, Volume 1, except for the structural analysis. The latter is presented in a classified Volume 2 of Report PWA-2320, because of the classification of some properties of columbium-1 per cent zirconium.

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I. INTRODUCTION

Rankine-cycle space powerplants require that the working fluid be condensed either directly inside radiators or indirectly in compact heat exchangers. In the most common designs of both types of condensers, the condensing occurs inside of tubes. Since flow instabilities inside condensing tubes might cause large pressure oscillations and inventory changes within the system, investigations were needed to determine whether or not such instabilities exist, and to eliminate them if they were found to be present and detrimental.

An experimental study reported in Volume 2 of Report PWA-2227* concluded that slugging occurred with condensing flow inside of tubes and that large pressure oscillations resulted. In order to supplement the findings from that study, an additional experimental program was conducted to investigate effects of tube diameter and gravity on slugging in condensing flow, and to investigate means for reducing the pressure oscillations caused by slugging.

Many space powerplants under consideration having compact indirect condensers use a number of independent radiators and cooling loops for condensing the flow of the Rankine cycle. Coolant loss could be caused by meteoroid punctures in one or more radiator segments. Therefore, an investigation was also made of the effects of loss of coolant to different shell-tube condenser sections that might be associated with such independent radiator segments.

*Wyde, S.S., and H.R. Kunz, Experimental Investigation of Heat Rejection in Nuclear Space Powerplants, Report PWA-2227, Volume 2, Condensing Flow Stability Studies, Report Period June 1, 1962 to May 31, 1963

II. SUMMARY

An experimental program was conducted to investigate stability of condensing steam flow inside of tubes to aid in the design of Rankine-cycle space powerplants. As a result of the investigation it can be concluded that slugging is likely to occur inside tubes in zero gravity at high condensing rates. This slugging causes pressure oscillations which must be taken into account in the powerplant component structure. In addition, slugging might cause possible pump cavitation problems. These problems may be more severe in ground tests of a space powerplant. The magnitude of the pressure oscillations can be reduced by the use of inserts in the tubes. Furthermore, meteoroid puncture in a radiator segment with a subsequent loss of coolant to one of a number of parallel condensers might result in violent pressure oscillations. These oscillations could also lead to pump cavitation and system failure. Oscillations can be reduced by the use of orifices in the condensing tube exits.

The program was divided into four parts: 1) glass-tube tests to coordinate visual observations with transient pressure measurements, 2) single-metal-tube tests to determine the effects on slugging of gravity, tube diameter, and inserts within the tube, 3) simulated segmented shell-tube indirect condenser tests to determine the effects of partial coolant loss with different orientations and cooling arrangements, and 4) simulated condensing-radiator tests to determine the effects of gravity on condensing flow in this configuration.

The glass-tube tests were made with one, two, and three condensing tubes in parallel, with the test section oriented either horizontally, tilted 2 degrees downhill, or tilted 2 degrees uphill. Flow oscillations were found to be present and a high speed motion picture showed that these oscillations were due to slugging. Pressure transducers recorded the frequency and magnitude of oscillations during slugging flow. These oscillations occurred more frequently when the test section was oriented at a slight uphill slope than when in the level orientation. At a slight downhill slope, no pressure oscillations occurred.

The single-metal-tube tests were conducted with condensing tubes having constant inside diameters of 0.180, 0.305, and 0.430 inch, and with a tapered condensing tube whose inside diameter varied from 0.50 inch at the inlet to 0.1875 inch at the exit. In addition, three different inserts were installed and tested inside one of the constant diameter tubes. Effects of angle of tube inclination, condensing flow rate, and coolant flow rate were investigated using these seven different test sections. In general, the magnitude of pressure oscillation caused by slugging decreased as the angle of tube inclination decreased from vertical upflow to vertical downflow. However, the smallest constant diameter tube showed minimum magnitude of oscillation in the level orientation

at one set of conditions. Thus significantly greater oscillations occurred in both the vertically up and vertically down orientations than in the horizontal orientation. Slugging did occur to some extent in most tests with vertical downflow orientation which seemingly would result in more stable conditions than those anticipated in zero gravity. Therefore, slugging could exist in actual space powerplants.

The tapered-tube test section and the inserts were tested in an attempt to reduce or eliminate slugging. The three inserts tested were a twisted tape insert and both a slotted and a nonslotted concentric tubular insert. The inserts tended to reduce the magnitude of oscillations, but the tapered diameter tube did not.

The simulated shell-and-tube condenser test section, which consisted of three tubes with segmented cooling jackets, was tested to determine effects on pressure and temperature fluctuations when the coolant was shut off in different segments. Two different cooling arrangements were tested, one which simulated a condenser cooled by different radiator loops in different axial sections, and the other which simulated a set of condensers connected in parallel, each being cooled by a separate radiator loop. Different test section orientations, different header sizes, and the use of orifices in the tube exits were also investigated.

These tests indicated that large pressure fluctuations would occur if considerable amounts of vapor entered the exit manifold. This detrimental effect occurred only when the second type cooling arrangement was used without orifices installed in the tube exits. The use of orifices apparently allowed only a small amount of vapor to enter the exit manifold. Thus, to avoid high amplitude pressure oscillations in the event of meteoroid puncture of a radiator loop, devices which restrict vapor flow (such as orifices) at the condensing tube exits are desirable with parallel condenser operation. The test section orientation also affected the results since in some cases the liquid head in the exit manifold prevented vapor from entering the exit manifold.

The series of simulated condensing-radiator tests was run using a configuration consisting of three tubes of 0. 180-inch inside diameter stacked in a vertical plane with the tube axes horizontal. The vertical distance of 6 inches between successive tubes created a pressure differential between the tube exits. In these tests, the total steam flow rate was decreased and temperatures at the tube inlets were recorded. The results indicated the value of low steam flow rate which permits sufficient liquid head in the exit manifold to cause liquid to flow back through the bottom tube. During this testing pressure oscillations similar to those associated with slugging in other parts of the program were found to be present. No additional instabilities were uncovered.

III. TEST EQUIPMENT

The experimental program described in this report used the test facility described in Volume 2 of Report PWA-2227. The glass-tube configuration and simulated direct-condensing radiator configuration discussed here are described in the same report. In addition, the following configurations were tested: single metal condensing tubes with constant inside diameters of 0.180, 0.305, and 0.430 inch; a condensing tube of 0.430 inch diameter with twisted tape and tubular inserts; a single metal condensing tube of tapered diameter; and a configuration with three parallel tubes to simulate a shell-tube condenser. Pressure transducers were used in these tests to determine the magnitude and frequency of pressure oscillations. Transient temperature measurements were also made for tests on some configurations.

A. Description of Facility

A schematic flow diagram of the facility is shown in Figure 1. Wet steam was supplied from a plant boiler to shutoff gate valve V_1, at a pressure of 150 psia. The steam and liquid water were then separated by two separators in series. The separated liquid flowed to the drain through a steam trap and the steam flowed through a filter before splitting into two branches.

In one branch the steam was superheated by a resistance heater. The superheated steam pressure was regulated by either of two regulating valves, V_4 or V_5, and the steam flow was metered by a standard orifice. The superheated steam was partially controlled by valve V_8 before entering a mixing chamber. In the other branch the steam was condensed to subcooled water and the flow was metered and controlled by valve V_7 before entering the mixing chamber. The desired steam quality at the test section was produced by controlling the temperatures of the two branches before mixing and the ratio of superheated steam flow to subcooled water flow.

The test sections were cooled by water pumped through cooling jackets concentric with the condensing tubes. The cooling flows of individual cooling lines were metered. The condensate flow from the test section was controlled by valves V_{9a} and V_{9b} and metered before entering the drain.

Thermocouples, Bourdon gages, manometers, and flowmeters were used at strategic locations shown in Figure 1 for the simulated direct-condensing radiator configuration. These measuring devices enabled the determination of pressure, temperature, and flow of the coolant and the condensing fluid at a number of different locations. Two types of transducers were used for transient pressure measurements. One type was a Consolidated Electric Corporation (CEC) transducer which could sense both pressure level and pressure variations. The CEC transducer and its galvanometer system could sense frequencies to 1000 cycles per second. The second type of transducer was a Photocon transducer that was used to sense only pressure variations. This transducer and the system used in conjunction with it could sense frequencies to 3000 cycles per second. A Heiland oscillograph was used to record the output of transducers and thermocouples used in transient tests. Pressure fluctuations were monitored during the tests by viewing the transducer outputs through oscilloscopes. Additional details of the facility are described in Volume 2 of Report PWA-2227.

B. Description of Test Sections

The following sections describe each of the test configurations in detail.

1. Glass-Tube Configurations

Figure 2 shows a photograph of the glass-tube configuration. The glass branches consisted of precision borosilicate (Pyrex) glass tubing of 0.026-inch wall thickness, 0.240-inch outside diameter and 25.8 inches length, with cooling jackets of 0.0625-inch wall thickness and 1/2-inch outside diameter. This resulted in a cooling jacket annular height of 0.0675 inch. The inlet manifold was a plain stainless steel tube 2 inches in outside diameter with welded branch connecting tees. The entrances of the tees were rounded to a radius of 0.062 inch. The tees for a branch would be capped off if that branch were not to be used. The inlet manifold had two drain cocks and a threaded cap on the end for cleaning and inspection, and was thermally insulated for tests. The branches were connected to the tees by Swagelok nuts and Teflon ferrules. Brass fittings were used to prevent scratching and weakening the glass. The exit manifold was made of 1/2-inch Swagelok tees and 1/2-inch diameter tubing.

The steam flow entered at right angles to the inlet manifold and proceeded through a flow straightener. The large diameter inlet manifold acted as a reservoir to provide equal flow through each of the three branches.

2. Single-Metal-Tube Configurations

The different single metal tube test sections used are described below. Each test section had stainless steel pressure taps near the inlet and exit in order to attach manometer lines and transducers.

a) Constant-Diameter Condensing Tube - Three different constant-diameter condensing-tube test sections were made with copper condensing tubes and copper cooling jackets. The cooling jackets were connected to the condensing tube and cooling feed lines with Swagelok heat exchanger tees.

The flow entered each test section from a larger tube connected to the test section by a reducing union. The inlet to each test section was rounded to a radius of approximately 1/16 inch.

The main dimensions for these constant diameter sections are summarized below:

Condensing tube inside diameter, inches	0.180	0.305	0.430
Condensing tube outside diameter, inches	0.250	0.375	0.500
Condensing tube length, inches	40.25	63.0	63.0
Cooling jacket inside diameter, inches	0.430	0.555	0.670
Cooling jacket outside diameter, inches	0.500	0.625	0.750
Cooling jacket length, inches	35.0	51.5	51.5
Cooling annular height, inches	0.090	0.090	0.085
Overall cooled length, inches	37.0	56.0	56.0
Entrance tube inside diameter, inches	0.430	0.430	0.670

b) Swirler Insert Test Section - The 0.430-inch inside diameter test section described above was modified by inserting a stainless steel twisted tape 0.094 inch thick and 0.430 inch wide into the tube. The twisted tape shown in Figure 3 had a length of 58 inches and a pitch of 1.5 inches. The swirler occupied the last 92 per cent of the length of the condensing tube. A radial pin brazed to the tube wall at the downstream end prevented the swirler from moving downstream, and a tight fit within the tube prevented the swirler from turning.

c) Tubular Insert Test Sections - Two different tubular inserts were made to fit inside the 0.430-inch inside diameter tube described in a). The inserts shown in Figure 3 were made of stainless steel tubes 0.191 inch in outside diameter, and 0.01 inch in wall thickness. Wire spacers were soldered to the tube in order to center the insert in the condensing tube. One insert had circumferential slots cut around one-half of the circumference approximately every 0.25 inch and the other was left plain. Each insert was 24 inches long and occupied the last 38 per cent of the condensing tube. A radial pin located in the downstream end of the condensing tube prevented the inserts from moving downstream.

d) Tapered Diameter Tube - A photograph of the tapered tube configuration is shown in Figure 4. Both the condensing tube and coolant tube were made of aluminum. The condensing tube had an inside diameter of 0.50 inch at the inlet and 0.1875 inch at the exit. The length was 43.0 inches and the wall thickness 0.035 inch. The coolant tube had an inside diameter of 0.656 inch at the inlet and 0.375 inch at the exit. Its length was 38.5 inches and its wall thickness was 0.046 inch. The coolant annulus was therefore approximately 0.10 inch high. The coolant jacket was attached to the condensing tube by using an epoxy cement to seal the annular spaces on both ends. The cooling lines were also attached to the coolant jacket with this epoxy cement. The steam flow entered the test section from a 0.56-inch inside diameter tube which was connected to the test section by a reducing union. The inlet to the test section was rounded.

3. Simulated Shell-Tube Configuration

The simulated shell-tube configuration shown in Figure 5 comprised an inlet and an exit manifold connecting three condensing tubes in parallel. The copper condensing tubes were 0.430 inch in diameter, 0.035 inch in wall thickness, and 63 inches long. Each condensing tube had three concentric tubular cooling jackets made from copper tubes 0.750 inch in outside diameter, 0.040 inch in wall thickness, and 12.5 inches long. The cooling jackets were connected to the condensing tubes and cooling lines by Swagelok heat exchanger tees. Each cooling segment had an overall cooling length of 17 inches and a cooling annulus 0.085 inch high.

Two inlet manifolds of different lengths were used. One was 5 inches long and the other 6 inches long. Both were constructed from 4-inch copper tubing, 4-inch copper caps, and steel flanges. Either manifold could be bolted to a steel plate containing inlet tees connected to the condensing tubes with Swagelok nuts. The tees had rounded inlets and were spaced in line with a center-to-center distance of 1.625 inches between center tee and each of the two end tees. The flow entered the inlet manifold through a 0.5-inch outside diameter tube located in the face opposite the tube inlet plate. The manifold inlet was not in line with any of the tube inlets. The inlet manifolds were insulated during testing.

The 5-inch long exit manifold was constructed of two 4-inch copper caps and 4-inch copper tubing. Tees to connect the condensing tubes to the exit manifold were brazed directly to one of the copper caps. Also, a 0.25-inch outside diameter tube was brazed in the side of the exit manifold for the flow exit. Bleed vents and pressure taps were installed in all manifolds, and pressure taps were installed near the exit of each condensing tube.

This test section had pressure transducers connected to the pressure taps located in the inlet manifold, exit manifold, and exits of each tube. The inlet manifold pressure was obtained from a precision glass tube manometer. Four chromel-alumel thermocouples with 1/16-inch diameter sheaths were installed to an immersion length of 5/8 inch inside each condensing tube. These were spaced with one at the tube inlet and one after each cooling segment. In some tests, orifices 0.1 inch in diameter were inserted in the exit of each condensing tube.

4. Simulated Condensing-Radiator Configuration

This configuration was the three-metal-branch configuration reported on in Volume 2 of Report PWA-2227. A photograph of this test section is shown in Figure 6.

The steam flow entered at right angles to the inlet manifold of 2-inch outside diameter and proceeded through a flow straightener. The large diameter inlet manifold acted as a reservoir to provide equal flow through each of the three branches which were connected to the manifold with welded tees. The collector manifold for the three branches had an outside diameter of 1/2 inch. The inlet manifold had two drain cocks and a threaded cap on the end for cleaning and inspection, plus viewports to visually inspect the inside during testing. The inlet manifold was thermally insulated for tests.

The dimensions of the branches were identical to those for the 0.180-inch inside diameter single condensing tube configuration described above. The center-to-center distance between branches was 6 inches.

IV. EXPERIMENTAL PROGRAM AND TEST RESULTS

The experimental program was divided into four parts: glass-tube tests, single-metal-tube tests, simulated shell-tube configuration tests, and simulated condensing-radiator configuration tests. The glass-tube tests provided a method of connecting visual observations of slugging with transient measurements from pressure transducers. The single-metal-tube tests provided a method of determining effects of tube diameter, condensing flow rate, coolant flow rate, angle of tube inclination, and use of inserts on pressure oscillations caused by slugging. The simulated shell-tube tests showed how different cooling arrangements, use of orifices, size of inlet header, and test section orientation influenced pressure and temperature variations during periods when coolant flow to part of the condenser was shut off. The simulated condensing-radiator configuration tests showed the effects of gravity upon flow distribution when the manifolds axes were oriented in the vertical plane.

A. Glass-Tube Configurations

Flow observation tests using a test section with glass tubes were reported in Volume 2 of Report PWA-2227. Movies were taken which showed that rapid changes in the position of the final liquid-vapor interface occurred during otherwise steady operation. However, the movie speed was not fast enough to determine whether slugging occurred in these tests. Also, a run with the test section at a slight downward slope did not indicate any rapid pulsations.

In order to supplement these observations, additional tests were run using glass tubes. First, high speed motion pictures were taken which indicated that slugging was occurring during the rapid pulsations previously observed. Tests were then run using pressure transducers to record the magnitude and frequency of the pulses. These tests were run with one, two, and three tubes to determine whether the number of tubes affected the pressure fluctuations. Also, the test sections were oriented in three different positions to observe the effects of gravity. Table 1 contains the conditions and condensing lengths for all tests run on the glass tube configurations. All tests were run at a tube inlet static pressure of approximately 20 psia. Because of the similarity of the results for a number of the runs reported, only particular runs were used to demonstrate the various features observed in the data.

A sequence from the high speed movies is shown in Figure 7. Individual frames show the condensate film initially calm, with waves formed, rapidly becoming turbulent, returning to a calm state, and finally showing back flow to reveal the final liquid-vapor interface. Although the movies did not show the wave bridging across the diameter of the tube to form a slug, the action shown is similar to parts of slug flow sequences described in Report PWA-2227. Significantly, the main action occurring between the second and third frames took only 0.0044 second and thus a normal speed movie would only indicate a blur for this motion. The entire sequence occurred within the short span of 0.128 second.

Figure 8 contains typical curves of pressure at tube exits versus time, for one, two, and three tubes oriented in 2° uphill orientation. All three curves indicate that a set of oscillations occurred approximately every two seconds with a calm period between each set. The effect of number of tubes can be seen from the increase in the number of oscillations in each set as the number of tubes increased. This can perhaps be explained by the occurrence of a vapor slug collapsing in one tube reducing pressure in all the tubes thereby providing impetus for slugging to occur in another tube, and so on. It can also be observed in this figure that the magnitude of pressure oscillation is approximately the same for one, two, and three tubes.

Figure 9 shows that the pressure fluctuations at various locations in a three-tube test section are approximately in phase.

Figure 10 shows the effect of gravity on the pressure fluctuations for a single tube. At a slight downhill slope of 2°, the tube exit pressure was nearly constant, indicating that slugging did not occur. At a level orientation, sets of oscillations occurred with a period of about 5 seconds between sets. When the tube was oriented for a slight uphill flow, the period between sets of oscillations decreased to about 2 seconds. Although the case presented for a 2° downhill slope had considerably less condensing steam flow than the other two tests, the sets of tests for 2 and 3 tubes which had approximately equal condensing flow per tube indicated similar results.

B. Single-Metal-Tube Configurations

The effect of gravity on pressure oscillations observed in the glass-tube tests indicated that further tests with variation of tube inclination were needed at higher condensing flow rates. Therefore, the rig was modified in order to vary the angle of test section inclination from a vertical upflow position (+90°) to a vertical downflow position (-90°). Three different metal tube test sections with inside diameters of 0.180, 0.305, and 0.430 inch were used to determine the effects of tube diameter on pressure fluctuations. A tapered-diameter test section was also constructed to determine whether decreasing the cross-sectional area as the vapor condensed could reduce pressure oscillations. Three other test sections with inserts were also tested in an attempt to discover methods of overcoming slugging within a condenser tube.

Tables 2 through 8 contain the test conditions of the different single-metal-tube tests. Each configuration was tested at two different condensing steam flow rates to determine the effect of velocity on pressure oscillations. Also, in the lower condensing flow rate tests, two different coolant flow rates were used to determine the effects of that variable. All tests were run at a tube inlet static pressure of approximately 50 psia. The condensed liquid at the exit of the tube was subcooled between 100 and 200°F for these tests. There was no evidence of any effects caused by the different magnitudes of subcooling at the tube exit on the slugging phenomenon.

Figure 11 contains plots of the average magnitude of pressure oscillation in the tube exit versus the angle of tube inclination for the 0.18-inch inside diameter tube tests and for the different test conditions shown in Table 2. This average magnitude of pressure oscillation was obtained by calculating the difference between the peak and adjacent minimum pressures for a number of times and averaging this difference. An adequate number of differences was selected to make the average insensitive to the number selected. The high condensing flow curve indicates that the magnitude of oscillation was minimum in the level orientation and the magnitude of oscillation increased as the tube angle of inclination was raised or lowered. These three curves indicate that the condensing flow rate had a large effect upon the magnitude of pressure oscillation, whereas coolant flow rate had only a slight effect. Also, at downhill slopes and at the level positions, oscillations were either infinitesimal or small for the low condensing flow rate of 0.0035 lb/sec and either cooling flow rate. An increase in slope upward increased the magnitude of oscillation.

Figure 12 shows the magnitude of pressure oscillation in the inlet header. The pressure oscillations at the inlet were considerably lower in magnitude than those at the exit. Apparently the oscillations are damped by the uncondensed vapor contained in the small-diameter tube upstream of the location where the slugging occurred.

Figure 13 contains typical curves of pressure at the tube exit versus time for the high condensing flow tests. Figure 14 contains similar curves of tests with the low condensing flow of 0.0035 lb/sec and a coolant flow of 0.80 lb/sec. The test results for the low condensing flow and a coolant flow of 0.36 lb/sec were similar to those shown in Figure 14.

Curves of average magnitude of pressure oscillation versus angle of inclination at the exit and inlet of the 0.305-inch inside diameter tubes are shown in Figures 15 and 16 with the test conditions shown in Table 3. The same type curves for the 0.430-inch inside diameter tube are shown in Figures 17 and 18 with test conditions shown in Table 4. The high condensing flow rates for each of these two test sections resulted in approximately the same inlet steam velocity as did the two sets of tests at the lower condensing flow rates. The curves at the respective high and low steam inlet velocities for these two test sections were similar. Also, the magnitude of pressure oscillation at the inlet was similar to that at the exit for each configuration. This result was considerably different from that for the 0.180-inch inside diameter tube tests. The larger diameters coupled with the probability that the condensing lengths are shorter could explain why the oscillations were not damped at the inlets in these tests. In general, the magnitude of pressure oscillation decreased as the angle of inclination decreased.

Typical pressure versus time curves for the 0.430-inch inside diameter tube tests are shown in Figures 19 and 20. The Figure 19 curves are for high condensing flow and those of Figure 20 for low condensing flow, high coolant flow. At the low condensing flow, low coolant flow, the results were similar to those shown in Figure 20. The results for the 0.305-inch inside diameter test section were also similar to these curves at the corresponding test conditions of coolant flow and inlet steam velocity.

Significantly, at an angle of inclination of -90°, the pressure oscillations were relatively small and increased rapidly as the angle of inclination increased. This trend is much different from that indicated for the high condensing flow tests in the 0.180-inch inside diameter tube at approximately the same inlet steam velocity. This indicates a possible diameter effect upon slugging.

Most of the downflow tests indicated some pressure oscillation even though the magnitude was small. This result indicates that slugging is likely to occur under zero gravity conditions if an annular flow pattern exists within the condensing tube. Since the condensing film would tend to be thinner in the downflow case because of the effect of gravity, slugging would be more likely to occur under zero gravity.

One concept for decreasing or eliminating slugging is to induce a tangential velocity component in the condensing fluid to prevent transverse waves from being produced in the condensate layer. Thus, a twisted tape or swirler was inserted in the 0.430-inch inside diameter tube to induce a tangential velocity in the condensing fluid. A series of tests was run on this configuration at the test conditions shown in Table 5. Figures 21 and 22 show average magnitude of pressure oscillation versus angle of tube inclination at the tube exit and inlet for this test section. A comparison of Figure 21 with Figure 17 shows that the tendency of the swirler was to reduce the magnitude of pressure oscillation at the tube exit for the tests with upflow angles of inclination, but had little or no adverse effect for tests with level or downflow orientations. A comparison of Figures 22 and 18 indicates that the swirler has a much greater effect in reducing the magnitude of pressure oscillation at the tube inlet. This is probably due to a damping effect of the swirler on the transmission of pressure oscillations along the tube in the two-phase region.

Figure 23 shows typical curves of pressure at the tube exit versus time at the high condensing flow rate.

Another concept for decreasing or eliminating slugging is to provide solid boundaries to contain the condensate film and thus prevent waves from growing to form slugs. In order to test this concept, two test sections were constructed by inserting a 3/16-inch outside diameter tube into the 0.430-inch inside diameter condensing tube. Slots were cut into one insert tube while the other was left solid. These sections were tested only in the level orientation. Tests on the slotted insert section showed no pressure oscillations for long periods (5 minutes or more). However, occasionally oscillations would occur. Figures 24 and 25 show typical curves of pressure at the tube exit versus time for two flow conditions, during periods of calm and periods of oscillation. The test conditions are shown in Table 7.

During the periods of oscillation, the magnitude of pressure oscillation of the slotted insert test section showed improvement over the plain 0.430-inch inside diameter tube without swirler section for similar flow conditions.

The nonslotted insert test section also showed improvement over the 0.430-inch inside diameter tube without swirler section. Figure 26 shows typical curves of pressure in the tube exit versus time for three different test conditions shown in Table 6.

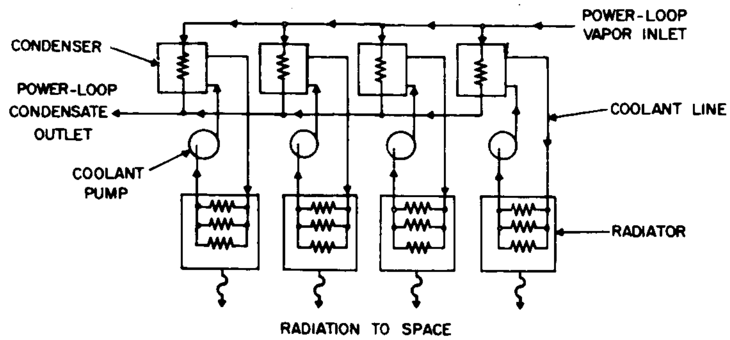
A tapered-diameter tube test section was also tested to determine whether decreasing the tube diameter as the condensate film increases could reduce the slugging. Figures 27 and 28 show curves of magnitude of pressure oscillation in the tube exit and inlet as a function of angle of tube inclination. Test conditions are presented in Table 8. Since diameter and velocity varied over a wide range along the test section, it is difficult to compare these curves directly with the other test sections. However, it appears that the tapered test section did not produce very favorable results in reducing pressure oscillations.

In some tests on the tapered tube, the pressure fluctuations measured at the inlet were greater than those measured at the exit. Apparently, the slugging occurred at such a point that the diminishing diameter over a relatively long length aided in damping the magnitude at the exit for these cases. Figure 29 shows typical curves of pressure in the tube exit versus time for one test condition.

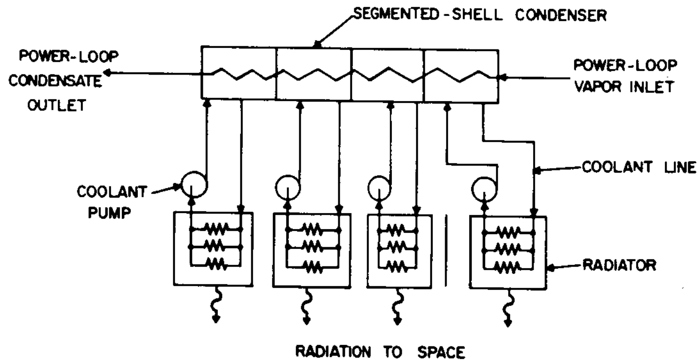
C. Simulated Shell-Tube Configurations

A test section was constructed to simulate a shell-tube type condenser with the condensing flow inside of the tubes. This type of condenser is presently considered the most likely type to be used in an indirect-condensing Rankine cycle space powerplant. In such a powerplant, a liquid coolant flows in one or more radiator loops to absorb the heat rejected by the Rankine cycle working fluid in one or more condensers. This heat is then rejected to space from the radiators.

The coolant for any condenser can either: 1) be provided from one distinct radiator loop (single-loop condenser) (see sketch), or 2) be provided from several radiator loops by segmenting the condenser shell side (multiloop condenser) (see sketch). Since each coolant loop is associated with a distinct radiator segment, a radiator puncture would result in no heat being rejected from the Rankine cycle working fluid of a single-loop condenser, but would result in at least partial condensation of the working fluid in a multiloop condenser.

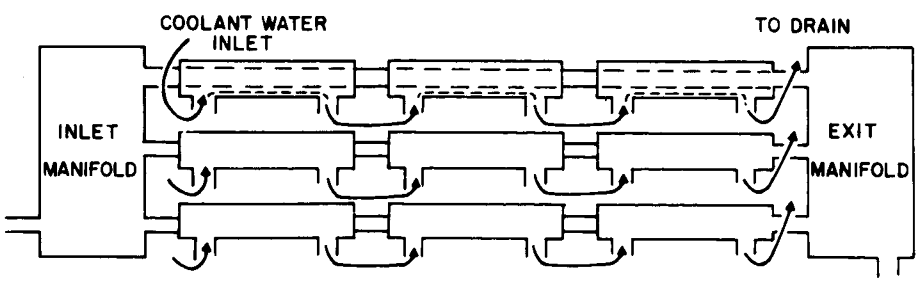


Single-Loop Condenser System



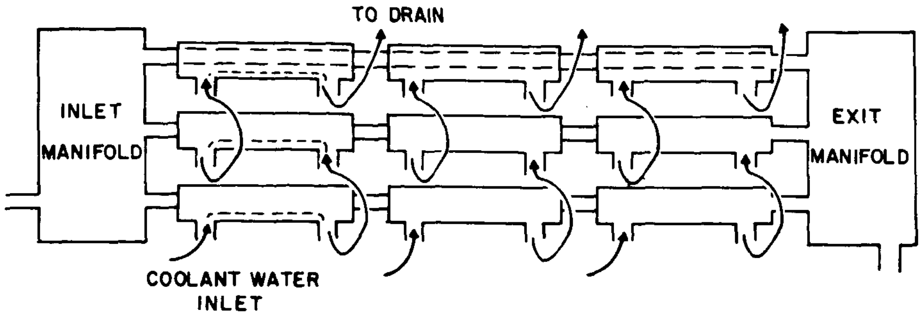
Multiloop Condenser System

In order to investigate effects from loss of coolant to either single-loop or multiloop condensers, the test section was constructed with the cooling jacket of each condensing tube divided into three axial segments. In order to simulate single loop condensers, the three cooling jackets from each tube were connected in series (parallel-to-tube cooling arrangement) (see sketch). To simulate multiloop condensers, the first axial segments of each one of the cooling jacket segments



Parallel-to-Tube Cooling Arrangement to Simulate Single-Loop Condenser

were connected in series. The same was done for the second and third axial segments (across-tube cooling arrangement) (see sketch). In



Across-Tube Cooling Arrangement to Simulate Multiloop Condenser

either cooling arrangement there were three distinct cooling lines with a three-way valve in each line, in order to bypass the coolant from the cooling jackets directly to the drain.

The test procedure was first to set the approximate conditions of condensing flow per tube at 0.020 lb/sec, coolant flow per line at 0.81 lb/sec, and tube inlet static pressure at 50 psia, and then to bypass the coolant from one of the cooling lines. After about 25 seconds, the valve was reopened. The cooling water trapped in the cooling annulus could boil off since the line was open to the drain. Transient measurements were made of tube exit pressures, inlet manifold pressure, exit manifold pressure, and four condensing fluid temperatures from each tube.

Three different test section orientations were used in this series. They were: 1) tube axes horizontal, tubes stacked in the vertical plane, 2) tube axes horizontal, tubes arranged in the horizontal plane, and 3) tube axes vertical. Orifices were installed in the tube exits for some tests. Also, two different size inlet headers were used. Table 9 contains a list of the different tests run using the simulated shell-tube configuration. Tables 10 through 32 contain the values of exit manifold pressure level, magnitude of pressure oscillation at various locations, and temperature levels of the 12 thermocouples as a function of time, for each test.

Prior to bypassing the flow from a coolant line, all tests exhibited pressure oscillations which had an average magnitude between 2 psi and 10 psi, caused by slugging flow.

The tests with the across-tube cooling arrangement showed different effects when each of the three cooling sections was shut off. However, no large effects were seen from the two different test section orientations, from the two different-sized headers, nor from the presence or absence of orifices in the tube exits. Therefore, a discussion of Tests Nos. 9.07, 9.08, and 9.09 can best show the effects of shutting off each cooling section on the pressure level, the magnitude of oscillation, and the temperature profile as a function of time. All of these tests were run with the tube axes horizontal and with the tubes stacked in the horizontal plane.

Figure 30 shows the pressure level in the exit manifold versus time for these three tests. When the coolant was bypassed from the cooling sections nearest the inlet manifold, the pressure level rose sharply and then decreased to approximately the initial level. Removing the cooling from the first third of a tube tends to increase the vapor inventory of each tube, and thus decrease the liquid inventory. However, the condensate flow across the exit valve (fixed setting during this test) would remain the same unless the pressure upstream of the valve increased. Since the incoming vapor cannot be condensed at the initial pressure until the final liquid-vapor interface has moved far enough downstream, there is a pressure buildup. As the final liquid-vapor interface moves downstream towards its new equilibrium location, complete vapor condensation can again occur at a lower pressure and the needed reduction of liquid inventory decreases, thus the pressure decreases until equilibrium is obtained. When the coolant valve was reopened, the reverse procedure occurred.

For the run in which the coolant was bypassed from the middle sections, the variation of pressure was similar but not as large since the final liquid-vapor interface was probably located near the beginning of this section. Removing the cooling from the sections nearest the exit manifold only decreased the level of subcooling, and therefore did not increase the vapor inventory. Thus, the pressure level remained virtually constant for this case.

Figure 31 shows the effects of shutting off the coolant to each of the three sections on magnitude of pressure oscillation. For the first sections, the effect was to decrease the magnitude of oscillation considerably while there was no discernible effect for the third section.

The magnitude of oscillation was highly sporadic for the middle section case. Typical curves of pressure in the exit header versus time during the periods of coolant shutoff for Tests 9.07 and 9.08 are shown in Figures 32 and 33.

The temperature profile as a function of time for the case where the coolant to the first section was shut off is shown in Figure 34. T_1, T_2, and T_3 were located at the inlets of the three tubes and indicated saturation temperatures. Variation of these three temperatures approximately corresponded to changes of saturation temperature with variations of pressure level. T_4, T_5, and T_6, which were located between the first and second cooling sections of the three branches, tended to vary as the pressure varied with the exception of T_6 during the first few seconds. The final liquid-vapor interface in Tube 1 was probably located upstream of T_6 while the interfaces in Tube 2 and Tube 3 were located downstream of T_4 and T_5. Shortly after the coolant was shut off, T_6 was at saturation temperature which indicates the final interface moved downstream of T_6.

T_7, T_8, and T_9 indicated that the flow was not evenly distributed amongst the three tubes as did T_{10}, T_{11}, and T_{12}. Apparently, Tube 2 had the highest condensing flow while Tube 1 had the lowest. This also confirms the conclusion concerning the interface locations mentioned in the preceding paragraph. Similar conclusions can be obtained from Figures 35 and 36 when each of the other two cooling sections was shut off. However, the flow maldistribution did not alter the gross effects of the tests. Large variations of T6 in Figures 35 and 36 indicate the transient shifting of the final liquid-vapor interface with respect to that thermocouple. The large temperature changes in the short time span indicate the rapid motion undergone by the final liquid-vapor interface.

In order to illustrate the effect of vertical stacking as opposed to horizontal stacking, Figures 37, 38, and 39 show mean pressure level in the exit manifold, magnitude of pressure oscillation in the exit manifold, and the 12 temperature levels, all as functions of time for Test No. 9.02. This test had vertical stacking and can be compared to the corresponding curves for Test No. 9.08 which had horizontal stacking. The temperature versus time curves were fairly similar except that the final liquid-vapor interface of Tube 1 (bottom tube) from Test 9.02 was located upstream of T_3 for a portion of that test. This shows that the liquid head in the exit manifold forced the liquid-vapor interface upstream in the bottom tube. The magnitude of oscillation was relatively low at 2 psi or less throughout the period the coolant was shut off in Test 9.02, where for Test 9.08 the magnitude of oscillation occasionally was as high as 7 psi. Although there were some differences between data from Tests 9.02 and 9.08, the main trends were similar.

Figures 40, 41 and 42 show mean pressure level in the exit header, magnitude of pressure oscillation in the exit header and the 12 temperature levelsversus time for Test 9.11. This test had horizontal tubes, horizontal stacking, across-tube cooling, and exit orifices. Figure 43 shows a typical curve of pressure in the exit header versus time during a period the coolant was shut off to the middle sections. These figures can be compared to those for Test 9.08 to show that inserting 0.1-inch diameter orifices in the tube exits had virtually no effect on test results for across-tube cooling. Throughout all of these tests the tube exits contained liquid, and therefore the use of orifices to reduce vapor flow into the exit manifold was not needed. The pressure drop across the orifice was approximately 0.7 psi for a liquid flow of 0.021 lb/sec per tube. This pressure loss can be compared with an estimated total pressure loss between manifolds of 0.6 psi based on previous running. Other tests with the across-tube cooling and with exit orifices showed trends similar to those indicated by this discussion.

In contrast to the across-tube cooling arrangement, the parallel-to-tube cooling arrangement showed large effects as to whether or not orifices were inserted in the tube exits, and whether the tubes were stacked in the vertical or horizontal plane. Figure 44 shows the effects of vertical stacking on magnitude of pressure oscillation in the inlet and exit manifolds when coolant to the middle tube and to the bottom tube was shut off, without orifices in the tube exits. The magnitude of oscillation increased greatly when coolant flow to the middle tube was stopped, whereas little change occurred for the case when coolant to the bottom tube was shut off. Figure 45 shows that the pressure levels in the exit manifold for these two tests increased after the valve was closed, and then decreased to a fairly constant level indicating the effects of increased vapor inventory. Figure 46 shows a typical curve of pressure in the exit header during a period when coolant to the middle tube was shut off. Violent pressure changes were occurring approximately every 0.2 second.

The temperature versus time curves for these two tests, Figures 47 and 48, indicate that the vapor entered the exit manifold for the test when the coolant to the middle tube was shut off (Test No. 9.16), but did not for the test when the coolant to the bottom tube was shut off (Test No. 9.17). Rapid condensation of vapor in the exit manifold apparently caused the violent oscillations which occurred in Test No. 9.16. The effect of the liquid head in the exit manifold apparently prevented vapor from entering the exit manifold when coolant to the bottom tube was shut off. For Test 9.16 the interface in the bottom tube shifted upstream and returned downstream of T_6 as equilibrium was reached. For Test 9.17 the interface in the bottom tube was located upstream of T_6 at the beginning of the test and then shifted downstream of T_6 after the coolant was shut off. The curve for T_{11} in Test No. 9.16 indicated that this thermocouple, located at the exit of the middle tube, was alternately exposed to subcooled liquid temperatures and saturation temperatures during the period when coolant to that tube was shut off. The thermocouples located in the cooled tubes exhibited no large changes in temperature throughout either test. Although the temperature level curves presented in this report do not show very rapid fluctuations in temperature, small variations were indicated in oscillograph traces. These rapid fluctuations were present generally when pressure fluctuations occurred.

Figures 49 and 50 show mean pressure level and magnitude of pressure oscillation in the exit manifold for Tests 9.19 and 9.20. These tests had conditions similar to those for Tests 9.16 and 9.17, respectively, except that 0.1-inch diameter orifices were inserted in the tube exits. Tests 9.17 and 9.20 for which the coolant to the bottom tube was shut off showed similar effects on pressure level and magnitude of oscillation. Also, the temperature level curves for Test 9.20, Figure 5, were very similar to those for Test 9.17. Both showed that the end of the bottom tube contained subcooled liquid throughout the period coolant to that tube was shut off. However, results for Test 9.19 for which coolant to the middle tube was shut off showed that the magnitude of pressure oscillation was as high as that for Test 9.16 only for brief periods, and was considerably lower except during these periods. Figure 52 shows a typical curve of pressure in the exit manifold versus time for Test 9.19 during a period in which high magnitude oscillations occurred. The temperature level curves for Test 9.19, Figure 53, were similar for those of Test 9.16 except for lack of large variations in T_{11}. Apparently the orifices used in Test 9.19 prevented liquid from reentering the middle tube once the coolant was shut off.

Figures 54 through 57 are curves for Test 9.23 in which the tube axes were vertical with downflow, the middle tube coolant was shut off, and orifices were present in the tube exits. The pressure level curve, Figure 54, indicates the same type of rise and fall as the other tests exhibited when vapor inventory was changed. The magnitude of pressure oscillation was relatively low as shown in Figure 55. A typical curve of pressure level during the coolant shutoff period is shown in Figure 56. The temperature level curves, Figure 57, show that during the period coolant to the middle tube was shut off, vapor from that tube did not enter the exit manifold. The low magnitude of oscillation conforms with results from the 0.43-inch inside diameter single tube in the downflow orientation.

D. Simulated Condensing-Radiator Configuration

Most radiators considered for space application employ a long inlet manifold with tubes branching off at right angles to the manifold flow direction. The manifolds for this type heat exchanger have a large aspect ratio whereas the manifolds feeding the tubes of a shell-tube type heat exchanger are short and wide. Also, the tubes quite often branch off in the direction of manifold flow for the shell-tube heat exchanger. The metal branch configuration described above simulates the radiator type condenser.

Tests were performed using this configuration oriented with the manifold axes vertical and the tube axes horizontal to determine under what circumstances the liquid head in the exit manifold could cause flow reversal in the bottom tube, and any associated pressure oscillations or instabilities that might result. The test procedure was to establish a condensing flow rate and to take transient measurements of temperature from a thermocouple installed at the inlet of each tube. This procedure was repeated for a series of tests with changes in condensing flow. Table 33 contains the test data for this series. The static pressure in the tube inlets was approximately 50 psia for these tests.

Figure 58 shows the curves of temperature at tube inlets versus condensing steam flow. The top and middle tubes indicated saturated temperatures at their inlets throughout the entire flow range. However, the curve for the bottom tube shows a sharp shift from saturated vapor temperature to subcooled liquid temperature as the total flow was lowered. The subcooled liquid temperature at the bottom tube inlet indicated that liquid backflow occurred in the bottom tube.

An analysis was made in order to illustrate the effect of liquid head in the exit manifold and the pressure loss from inlet manifold to exit manifold on this flow reversal. In order to analyze the problem, the flow distribution between the tubes must be determined and this in turn depends upon the pressure distribution. The static pressure in the inlet manifold can be considered uniform since the header was relatively large and contained only vapor. However, the static pressure at the exit of each tube was different due to the liquid head in the collector. Therefore, the pressure differential between header and collector of the bottom tube was six inches of water greater than that of the middle and twelve inches of water greater than that of the top tube.

Figure 59 shows how pressure difference from header to collector varies with flow for test conditions very close to those used in this series of tests. The original data for this curve is contained in Volume 2 of Report PWA-2227 (Figure 23), and was taken for a single tube installed in the same inlet and exit manifolds.

Total flow rates for two points of interest can now be determined. The first point is the point of minimum pressure difference between header and collector for the bottom tube. Figure 59 shows a minimum pressure difference of -1.0 inch at a condensing flow of 0.001 lb/sec. If this were the case in the bottom tube, then the flow in the middle and top tubes could be determined by adding the collector head effect to this pressure difference and would be 0.0032 and 0.0040 lb/sec respectively. The total flow would then be 0.0082 lb/sec. This is approximately the total flow where the temperature versus flow curve for the first tube starts to drop (Figure 58).

A similar analysis shows that when no flow occurs in the bottom tube, the total flow for the other two tubes would be approximately 0.0075 lb/sec which is also close to the flow value at which the temperature vs flow curve of the bottom tube starts to drop. Therefore, it can be concluded that the liquid head in the exit manifold caused the flow reversal in the bottom tube as flow was decreased.

Transient measurements of pressure in the exit manifold were also recorded for these tests. Figure 60 shows that the average magnitude of pressure oscillation in the exit manifold did not vary greatly with condensing-flow rate.

V. SUMMARY OF RESULTS

The following section summarizes the main effects observed from the test results:

A. Glass-Tube Configuration

The violent pulsing observed by eye and through pressure transducer recordings is caused by slugging. A slight uphill slope increased the frequency of slugging and a slight downhill slope practically eliminated slugging for the low condensing-flow rates used.

B. Single-Metal-Tube Configuration

The following effects of inclination angle, tube taper, a swirler insert, and concentric tube inserts on pressure fluctuation were determined from the single tube tests:

1. Angle of Tube Inclination

In general, pressure fluctuations increased in the single-tube configurations as the angle of tube inclination increased from 90° downflow to 90° upflow. The high condensing-flow rate in the smallest diameter tube tested (0.180-inch inside diameter) was an exception to this observation. In this case the pressure fluctuations were a minimum at 0° inclination.

2. Tube Taper

The tapered tube did not show any large tendency to reduce fluctuations in comparison with the constant-diameter tubes.

3. Swirler Insert

A swirler inserted into the condenser tube reduced the level of pressure fluctuation with upflow inclinations.

4. Concentric Tube Inserts

A concentric slotted tube inserted in the condensing passage eliminated fluctuations for considerable periods of time, but fluctuations occurred occasionally. A similar tubular insert without slots also reduced fluctuations, but not as effectively as the slotted one.

C. Simulated Shell-Tube Configuration

The two different cooling arrangements showed different effects of test section orientation and use of orifices in the tube exits, as follows:

1. Across-Tube Cooling Arrangement

Similar results were obtained for all arrangements tested. The following are the test arrangements: tube axes horizontal, tubes stacked in the vertical plane both with and without orifices; tube axes horizontal, tubes arranged in the horizontal plane both with and without orifices; a smaller inlet header was also tested with orifices in tube exits.

However, the results varied with the particular cooling sections shut off.

a) Sections Nearest Inlet Header - Pressure oscillations in the exit manifold at an approximate pressure level of 50 psia reduced from the 2 to 10 psi associated with slugging prior to shutoff to 0 to 5 psi when the coolant was shut off. No vapor entered the exit header. Pressure level rose and then decreased, reflecting a change in the vapor inventory.

b) Middle Sections - Pressure oscillations varied sporadically between 0 and 10 psi at an approximate pressure level of 50 psia. No vapor entered the exit header. The pressure level rose and then decreased, reflecting a change in the vapor inventory.

c) Sections Nearest Exit Header - No appreciable changes occurred. Pressure oscillations were between 4 and 10 psi at an approximate pressure level of 50 psia. No vapor entered the exit header. These results could be expected since the last coolant section only subcooled the condensate and loss of subcooling has very small effect upon pressure losses.

2. Parallel-to-Tube Cooling Arrangement

a) Tube Axes Horizontal, Tubes Stacked in Vertical Plane

1) Without orifices in tube exits - When coolant to the three sections cooling the middle tube was shut off, pressure oscillations increased from the 2 to 10 psi associated with slugging prior to shutoff,to 30 to 35 psi at a pressure level of 50 psia. Temperature measurements indicated that steam was entering the exit manifold from the middle tube. Pressure level rose and then decreased, reflecting a change in the vapor inventory.

When coolant to the three sections cooling the bottom tube was shut off, the pressure oscillations remained between 4 and 10 psi. Temperature measurements indicated that vapor did not enter the exit manifold. The liquid head in the exit manifold was apparently high enough to maintain liquid in the bottom tube, but not high enough for the same result to occur in the middle tube.

2) With orifices in tube exits - When coolant to either the top or middle tubes was shut off, pressure oscillations were between 2 and 16 psi. Temperature measurements indicated that vapor from the uncooled tubes was entering the exit manifold.

When coolant to the bottom tube was shut off, pressure oscillations remained between 4 and 10 psi as before coolant shut off. No vapor entered the exit manifold.

b) Tube Axes Horizontal, Tubes Arranged in Horizontal Plane

1) Without orifices in tube exits - The coolant to the middle tube was shut off and the results were similar to the case mentioned above where the coolant to the middle tube was shut off,for vertical stacking,without orifices in the tube exits.

2) With orifices in tube exits - The coolant to the middle tube was shut off and the results were similar to the case mentioned above where the coolant to the middle tube was shut off, for vertical stacking, with orifices in the tube exits.

c) Tube Axes Vertical (With Orifices in Tube Exits) - When the coolant to the middle tube was shut off, pressure oscillations were between 4 and 10 psi. Temperature measurements indicated that vapor did not enter the exit manifold. The liquid head of the condensate from the two cooled tubes was apparently sufficient to maintain liquid in the uncooled tube. The pressure level rose and then decreased, reflecting a change in the vapor inventory.

D. Simulated Condensing-Radiator Configuration

The tests with this configuration indicated that pressure due to liquid head in the exit manifold can cause backflow. An analysis indicated that the approximate value of flow rate where backflow in a tube can occur, can be estimated from the pressure loss versus flow data measured in single-tube tests.

VI. CONCLUSIONS

The main conclusions drawn from this study are:

A. Slugging is likely to occur inside tubes in zero gravity at high condensing rates since some slugging did occur in downflow testing. Tube diameter, tube orientation and condensing flow rate affect the magnitude of pressure oscillation from slugging. The large pressure oscillations associated with slugging may cause structural problems in space powerplants and may cause pump cavitation. Techniques such as a large pressure drop occurring between the condenser and the pump may be required to overcome this problem.

B. The use of concentric tubular and twisted tape inserts can lower the pressure oscillations caused by slugging. Additional methods of reducing or eliminating oscillations should be investigated.

C. A meteoroid puncture in a radiator segment which is responsible for cooling an entire condenser can result in violent pressure oscillations from the uncondensed vapor mixing with subcooled liquid in other parts of the system. These pressure oscillations might cause pump cavitation and system failure. The use of orifices in the condensing tube exits can help minimize this effect. Further investigations are needed to determine effects of magnitude of subcooling on this problem.

D. The use of a segmented condenser in which all of the vapor passing through is condensed by several radiator loops would not result in very high pressure oscillations when one of the radiators is punctured,if adequate cooling capacity for complete condensation is present.

E. Large flow maldistributions and even backflow can occur in condensing radiators when operated under the influence of gravity, if the radiator is oriented with the exit manifold vertical. This effect is due to the pressure variation in the exit manifold caused by the condensed liquid head. The flow maldistribution does not appear to result in additional pressure oscillations.

F. More severe slugging might occur in condensers during ground tests than in space operation. Thus care should be taken to prevent serious damage to the pump and system during such tests on space powerplants.

APPENDIX 1
Tables

TABLE 1

Test Data For Glass Tube Configurations

Test Number	Orientation	Number Of Tubes	Condensing Steam Flow Per Tube (lbs/sec)	Cooling Flow Per Tube (lbs/sec)	Static Pressure at Tube Inlet (psia)	Steam Temp. In Inlet Manifold (°F)	Coolant Temperature (°F) In	Coolant Temperature (°F) Out	Steam Velocity At Inlet (ft/sec)	Condensing Length (inches)	Temperature In Exit Header (°F)
*1.01	Level	2	.00078	.32	19.2	226	59	64	86	20	90
1.02	2° Up	3	.00086	.28	21.1	230	60	64	87	18	95
1.03	2° Up	3	.00086	.28	21.2	238	60	64	88	20	101
1.04	2° Up	2	.00084	.29	21.0	222	60	62	85	20	104
1.05	2° Up	2	.00084	.29	21.6	239	60	63	84	20	105
1.06	2° Up	1	.00091	.27	21.2	242	60	61	93	20	119
1.07	2° Up	1	.00076	.27	20.8	228	60	61	77	20	126
1.08	Level	3	.00095	.26	20.1	227	60	64	100	20	91
1.09	Level	3	.00086	.26	20.0	280	60	63	98	20	89
1.10	Level	2	.00084	.27	19.7	223	60	63	93	20	110
1.11	Level	2	.00092	.27	20.5	241	60	64	102	20	115
1.12	Level	1	.00076	.27	20.0	225	61	62	80	20	104
1.13	Level	1	.00076	.27	20.6	237	60	62	79	20	109
1.14	2° Down	3	.00076	.31	20.8	194	58	60	80	17.5	80
1.15	2° Down	3	.00073	.32	20.6	249	58	61	78	17.5	86
1.16	2° Down	2	.00059	.28	20.8	225	61	63	62	24	83
1.17	2° Down	2	.00059	.28	20.6	237	61	63	61	25	81
1.18	2° Down	1	.00027	.27	19.7	234	61	61	29	25	83
1.19	2° Down	1	.00027	.27	19.4	224	61	63	30	23	93

*High Speed Movies Taken

TABLE 2

Single Tube Test Data
Constant 0.18-Inch Inside Diameter Tube

Test Number	Orientation	Condensing Steam Flow Per Tube (lbs/sec)	Cooling Flow Per Tube (lbs/sec)	Static Pressure at Tube Inlet (psia)	Steam Temp. In Inlet Manifold (°F)	Coolant Temperature (°F) In	Coolant Temperature (°F) Out	Steam Velocity At Inlet (ft/sec)	Temperature In Exit Header (°F)
2.01	+90°	.0104	.80	50.8	320	66	82	524	118
2.02	+30°	.0104	.82	50.7	323	66	82	524	119
2.03	0°	.0104	.82	50.6	307	66	81	514	130
2.04	-30°	.0104	.80	50.8	329	65	81	530	129
2.05	-90°	.0104	.81	50.3	324	65	82	531	130
2.06	+90°	.0035	.80	50.1	296	66	76	172	104
2.07	+30°	.0035	.80	50.9	295	66	72	169	88
2.08	0°	.0035	.80	50.4	291	65	72	171	96
2.09	-30°	.0035	.80	50.1	296	64	72	172	93
2.10	-90°	.0035	.81	50.5	296	64	72	173	116
2.11	+90°	.0035	.36	50.5	295	64	74	170	102
2.12	+30°	.0035	.36	50.7	295	64	76	171	91
2.13	0°	.0035	.36	50.6	290	63	76	169	101
2.14	-30°	.0035	.36	50.5	300	64	76	172	90
2.15	-90°	.0035	.36	50.7	310	63	76	178	120

TABLE 3

Single Tube Test Data
Constant 0.305-Inch Inside Diameter Tube

Test Number	Orientation	Condensing Steam Flow Per Tube (lbs/sec)	Cooling Flow Per Tube (lbs/sec)	Static Pressure at Tube Inlet (psia)	Steam Temp. In Inlet Manifold (°F)	Coolant Temperature (°F) In	Coolant Temperature (°F) Out	Steam Velocity At Inlet (ft/sec)	Temperature In Exit Header (°F)
3.01	+90°	.032	1.60	50.1	312	63	81	556	-
3.02	+30°	.032	1.60	50.4	330	64	87	570	131
3.03	+30°	.032	1.60	50.8	332	62	86	564	130
3.04	0°	.031	1.60	50.8	326	63	84	562	132
3.05	0°	.032	1.60	51.0	336	63	85	570	136
3.06	-30°	.032	1.60	50.6	316	63	96	553	135
3.07	-30°	.032	1.60	50.7	336	63	85	568	133
3.08	-90°	.032	1.60	50.4	323	64	86	561	138
3.09	+90°	.013	1.60	50.7	312	64	74	223	105
3.10	+30°	.013	1.60	50.7	310	64	75	223	106
3.11	+30°	.013	1.60	50.7	340	62	72	233	102
3.12	0°	.013	1.60	50.7	320	62	72	227	108
3.13	0°	.013	1.60	50.7	340	63	74	234	108
3.14	-30°	.013	1.60	50.5	312	62	72	224	106
3.15	-30°	.013	1.60	50.3	337	63	73	232	96
3.16	-90°	.013	1.60	51.0	314	64	74	221	133
3.17	+90°	.013	.81	50.2	307	61	83	222	110
3.18	+30°	.013	.81	50.5	310	61	83	224	109
3.19	+30°	.013	.81	50.7	320	60	80	228	108
3.20	0°	.013	.81	50.5	330	61	81	231	114
3.21	-30°	.013	.81	50.4	300	60	80	218	105
3.22	-30°	.013	.81	50.6	322	62	81	228	108
3.23	-90°	.013	.81	50.4	311	63	81	224	140

TABLE 4

Single Tube Test Data
Constant 0.43-Inch Inside Diameter Tube

Test Number	Orientation	Condensing Steam Flow Per Tube (lbs/sec)	Cooling Flow Per Tube (lbs/sec)	Static Pressure at Tube Inlet (psia)	Steam Temp. In Inlet Manifold (°F)	Coolant Temperature (°F) In	Coolant Temperature (°F) Out	Steam Velocity At Inlet (ft/sec)	Temperature In Exit Header (°F)
4.01	+90°	.052	1.63	50.5	290	63	100	440	154
4.02	+30°	.052	1.60	50.6	392	62	98	506	146
4.03	0°	.050	1.68	50.5	300	63	98	432	150
4.04	-30°	.052	1.60	50.9	290	64	100	436	158
4.05	-90°	.049	1.60	50.7	290	62	97	409	162
4.06	+90°	.028	1.60	50.5	286	63	82	233	120
4.07	+30°	.028	1.60	50.4	326	62	83	248	122
4.08	0°	.032	1.68	50.5	323	63	88	282	133
4.09	-30°	.028	1.60	50.6	330	64	83	249	133
4.10	-90°	.027	1.60	50.8	330	62	82	246	165
4.11	+90°	.028	.92	50.3	300	62	96	241	130
4.12	+30°	.027	.92	50.6	320	61	96	243	128
4.13	0°	.032	.92	50.7	300	61	101	276	143
4.14	-30°	.028	.92	50.5	326	62	96	248	142
4.15	-30°	.032	.92	50.5	326	63	100	283	148
4.16	-90°	.027	.89	50.6	330	62	96	242	176

TABLE 5

Single Tube Test Data
Constant 0.43-Inch Inside Diameter Tube With Swirler Insert

Test Number	Orientation	Condensing Steam Flow Per Tube (lbs/sec)	Cooling Flow Per Tube (lbs/sec)	Static Pressure at Tube Inlet (psia)	Steam Temp. In Inlet Manifold (°F)	Coolant Temperature (°F) In	Coolant Temperature (°F) Out	Steam Velocity At Inlet (ft/sec)	Temperature In Exit Header (°F)
5.01	+90°	.050	1.60	50.2	290	64	103	478	126
5.02	+30°	.047	1.60	50.7	298	62	98	400	121
5.03	0°	.050	1.60	50.6	286	65	103	422	128
5.04	-30°	.050	1.63	50.7	294	63	100	426	123
5.05	-90°	.050	1.59	50.6	290	63	100	425	124
5.06	+90°	.028	1.60	50.7	305	64	84	239	92
5.07	+30°	.028	1.60	50.7	328	60	96	248	90
5.08	0°	.032	1.60	50.4	326	64	87	283	98
5.09	0°	.028	1.60	50.4	324	65	84	247	93
5.10	-30°	.028	1.60	50.6	328	63	84	248	94
5.11	-90°	.027	1.59	50.7	330	63	84	256	93
5.12	+90°	.028	.92	50.4	331	64	100	250	103
5.13	+30°	.028	.92	50.5	328	60	96	248	98
5.14	0°	.028	.92	50.8	321	64	97	244	102
5.15	-30°	.028	.89	50.6	324	62	98	246	105
5.16	-90°	.027	.92	50.4	330	62	97	247	102

TABLE 6

Single Tube Test Data
Constant 0.43-Inch Inside Diameter Tube
with Nonslotted Tubular Insert

Test Number	Orientation	Condensing Steam Flow Per Tube (lbs/sec)	Cooling Flow Per Tube (lbs/sec)	Static Pressure at Tube Inlet (psia)	Steam Temperature In Inlet Manifold (°F)	Coolant Temperature (°F) In	Coolant Temperature (°F) Out	Steam Velocity at Inlet (ft/sec)	Temperature in Exit Header (°F)
6.01	0°	.021	1.60	53.0	360	52	75	191	115
6.02	0°	.028	1.60	52.6	372	52	75	253	110
6.03	0°	.028	.81	53.0	382	47	86	260	137

TABLE 7

Single Tube Test Data
Constant 0.43-Inch Inside Diameter Tube
with Slotted Tubular Insert

Test Number	Orientation	Condensing Steam Flow Per Tube (lbs/sec)	Cooling Flow Per Tube (lbs/sec)	Static Pressure at Tube Inlet (psia)	Steam Temperature In Inlet Manifold (°F)	Coolant Temperature (°F) In	Coolant Temperature (°F) Out	Steam Velocity at Inlet (ft/sec)	Temperature in Exit Header (°F)
7.01	0°	.021	1.60	54.0	379	52	75	192	121
7.02	0°	.021	1.60	53.6	380	52	75	194	126
7.03	0°	.028	1.60	53.4	391	51	75	255	112
7.04	0°	.028	1.60	52.2	391	51	75	261	112

TABLE 8

Single Tube Test Data
Tapered Tube

Inlet Inside Diameter = 0.50 Inch
Exit Inside Diameter = 0.1875 Inch
Length = 43.0 Inches

Test Number	Orientation	Condensing Steam Flow Per Tube (lbs/sec)	Cooling Flow Per Tube (lbs/sec)	Static Pressure at Tube Inlet (psia)	Steam Temperature In Inlet Manifold (°F)	Coolant Temperature (°F) In	Coolant Temperature (°F) Out	Steam Velocity at Inlet (ft/sec)	Temperature in Exit Header (°F)
8.01	+90	.019	.37	51.0	320	66	120	124	184
8.02	+30	.019	.38	50.3	288	66	120	116	170
8.03	0	.019	.38	50.7	286	66	115	115	168
8.04	-30	.019	.38	50.6	314	66	121	120	180
8.05	-90	.019	.40	50.7	312	66	124	120	182
8.06	+90	.013	.37	50.5	300	66	106	84	150
8.07	+30	.013	.38	50.6	294	66	106	83	146
8.08	0	.013	.38	50.7	290	66	106	82	148
8.09	-30	.013	.38	51.0	318	66	108	86	156
8.10	-90	.013	.36	50.6	319	66	109	86	176
8.11	+90	.013	.27	50.8	330	64	120	87	172
8.12	+30	.013	.27	50.1	294	65	120	84	170
8.13	0	.013	.27	50.3	309	63	120	86	170
8.14	-30	.013	.27	50.6	318	64	119	86	162
8.15	-90	.013	.27	50.1	313	66	117	85	182

TABLE 9

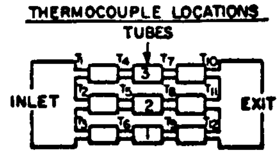
Table of Tests For Simulated Shell-Tube Configurations

Test Number	Cooling Arrangement	Orientation	Orifices In Tube Exit	Cooling Section or Tube Shut Off	Header
9.01	Across Tubes	Tube Axes	No	Nearest Inlet	Large
9.02		Horizontal,		Middle	
9.03		Vertical Stack		Nearest Exit	
9.04	Across Tubes	Tube Axes	Yes	Nearest Inlet	Large
9.05		Horizontal,		Middle	
9.06		Vertical Stack		Nearest Exit	
9.07	Across Tubes	Tube Axes	No	Nearest Inlet	Large
9.08		Horizontal,		Middle	
9.09		Horizontal Stack		Nearest Exit	
9.10	Across Tubes	Tube Axes	Yes	Nearest Inlet	Large
9.11		Horizontal,		Middle	
9.12		Horizontal Stack		Nearest Exit	
9.13	Across Tubes	Tube Axes	Yes	Nearest Inlet	Small
9.14		Horizontal,		Middle	
9.15		Horizontal Stack		Nearest Exit	
9.16	Parallel to Tubes	Tube Axes	No	Middle	Large
		Horizontal,			
9.17		Vertical Stack		Bottom	
9.18	Parallel to Tubes	Tube Axes	Yes	Top	Large
9.19		Horizontal,		Middle	
9.20		Vertical Stack		Bottom	
9.21	Parallel to Tubes	Tube Axes	Yes	Middle	Large
		Horizontal,			
		Horizontal Stack			
9.22	Parallel to Tubes	Tube Axes	No	Middle	Large
		Horizontal,			
		Horizontal Stack			
9.23	Parallel to Tubes	Tube Axes	Yes	Middle	Large
		Vertical			

TABLE 10

Data From Coolant Shutoff Tests on Simulated Shell-Tube Configurations. Test No. 9.01

THERMOCOUPLE LOCATIONS



Conditions:
1. Cooling arrangement across tubes
2. No orifices
3. Tube axes horizontal, tubes stacked in vertical plane
4. Condensing steam flow rate per tube prior to shutoff = 0.022 lb/sec
5. Cooling flow rate per tube prior to shutoff = 0.81 lb/sec
6. Cooling sections nearest inlet header shut off
7. Large inlet header

Time (seconds)	Mean Pressure Level (psig)	Magnitude of Pressure Oscillations (psi) Inlet Manifold	Exit Manifold	Tube 1 Exit	Tube 2 Exit	Tube 3 Exit	Mean Temperature Levels (°F) T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
0	35.5	8.0	4.5	7.0	13.0	6.0	313	305	304	280	290	203	172	190	114	120	161	100
1.0	36.0	10.0	6.6	10.0	16.0	9.0				275								
2.0	38.2	10.5	8.1	10.0	20.0	9.5	313	306	305	283	294	208	172	194	115	119	157	104
Valve Closed																		
2.5							315											
2.9												204						
3.0	49.5	10.0	7.1	11.0	22.0	12.0	320			301		210						
3.1												225						
3.2												245						
3.21												252						
3.25												256						
3.3												261						
4.0	49.0	9.5	7.5	13.5	19.5	12.0	322	312	313	301	311	313	164	199	117	118	150	106
4.755														230				
4.78														289				
4.8														297				
4.85														289				
4.9														244				
5.0	47.0	8.0	4.0	11.0	18.0	10.5				299				224				
5.344														231				
5.385														286				
5.44														243				
5.675														238				
5.73														296				
5.85														235				
6.0	46.0	12.0	6.5	10.0	17.0	10.0	315	307	308	296	306	307	182	287	150	118	146	113
7.0	43.8	12.0	7.5	12.0	17.0	10.5				290								
8.0	42.9	9.0	6.1	9.0	10.0	7.5	309	302	306	290	299	303	197	283	165	130	175	115
9.0	42.0	6.0	3.5	5.0	7.0	6.0				291								
9.5							309											
10.0	40.5	5.0	3.2	5.0	7.0	5.0	313	304	306	286	298	299	206	292	171	132	190	122
11.0	39.0	5.0	3.0	3.0	6.0	4.5				286								
12.0	37.6	7.5	4.5	6.5	7.5	6.0	315	306	306	283	293	295	206	286	176	145	186	132
13.0	37.0	4.0	2.5	4.1	5.5	2.5												
14.0	37.5	7.5	4.2	5.5	8.5	6.0	315	304	305	280	285	293	207	281	172	149	177	128
15.0	36.5	4.0	2.5	3.0	5.0	3.0												
16.0	37.0	7.0	4.1	6.0	8.0	5.5	315	315	306	282	295	294	202	284	180	148	175	130
17.0	37.0	5.0	3.1	4.5	4.0	4.5												
18.0	35.0	3.0	2.6	4.0	5.0	3.0	315	306	304	279	300	298	213	284	178	147	188	134
19.0	30.0	3.5	2.2	3.0	4.0	3.5												
19.1																131		
20.0	34.0	3.0	2.8	4.0	3.0	4.0	315	308	305	278	286	298	207	283	173	147	200	135
21.0	36.0	6.0	3.9	6.0	4.0	4.0												
22.0	36.5	5.0	4.1	5.0	5.0	5.0	316	308	307	280	285	300	203	281	163	151	189	130
23.0	35.5	7.0	3.9	4.0	5.0	4.5												
24.0	34.5	8.0	4.3	5.0	7.0	5.5	315	306	305	274	281	300	202	275	164	141	175	123
25.0	35.0	6.0	3.6	4.0	6.0	4.0												
25.6															175			
25.7												299	201					
25.8												295						
25.9												281			130			
26.0	27.5	9.5	3.9	2.0	6.0	6.5	312	304	303	266	275	277	210	270	136	143	185	123

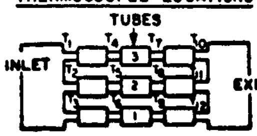
TABLE 10 (Cont'd.)

Time (seconds)	Mean Pressure Level (psig)	Magnitude of Pressure Oscillations (psi): Inlet Manifold	Exit Manifold	Tube 1 Exit	Tube 2 Exit	Tube 3 Exit	Mean Temperature Levels (°F): T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
Valve Reopened																		
26.15											269							
26.2											270							
26.33											257							
26.37											263							
26.4										251								
26.47										251	263							
26.5										253								
26.55											251							
27.0	17.5	6.0	4.3	4.0	6.5	5.0	306			245	247	250	183					
28.0	21.0	6.0	5.7	4.0	7.0	5.5	307	300	297	248	256	253	179	281	152	133	177	122
29.0	23.0	8.5	6.4	7.0	8.0	6.0	310			258	265							
30.0	27.5	9.5	7.3	10.0	11.0	9.5	312	304	301	265	272	272	168	184	156	123	152	119

TABLE 11

Data From Coolant Shutoff Tests on Simulated Shell-Tube Configurations. Test No. 9.02

THERMOCOUPLE LOCATIONS



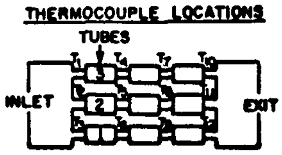
Conditions:
1. Cooling arrangement across tubes
2. No orifices
3. Tube axes horizontal, tubes stacked in vertical plane
4. Condensing steam flow rate per tube prior to shutoff = 0.022 lb/sec
5. Cooling flow rate per tube prior to shutoff = 0.81 lb/sec
6. Cooling sections shut off - middle
7. Large inlet header

Time (seconds)	Mean Pressure Level (psig)	Magnitude of Pressure Oscillations (psi) Inlet Manifold	Exit Manifold	Tube 1 Exit	Tube 2 Exit	Tube 3 Exit	Mean Temperature Levels (°F) T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
0	36.0	12	6.1	9.5	15	8.5	312	303	301	276	286	202	170	193	110	123	159	101
1	36.5	11.5	7.5	12.5	22.15	10					288	192	169	191	117.3	125	160.5	98
2	35.0	7	5.0	8.5	11	7	312	304	301	278	289	201	169.5	181	110	122.5	147	98
Valve Closed																		
3	37.5	0	1.0	0	0	0					295	179	169	208	94	117	158	99
3.5														290				
4.0	11.0	0	0	0	0	0	317	307		288	299.6	155	175	291	89	118.5	154	96
4.07									289									
4.2									180									
4.5									189									
5.0	11.0	0	0	0	0	0					299	181	180	285	101	123	167	95
5.2									210									
5.3									188									
6.0	39.8	0	0	0	0	0	317	306		287.5	297.5	180	183	290	105.5	127.5	207	95
6.145									194.5									
6.175									270									
6.89									269									
6.9									193									
7.0	39.5	0	0.8	0	0	0					297.5	166	193	290.5	105	121	208	95
8.0	39.0	0	1.0	0	0	0	315.5	306.5	192	286	295	180	211	290	107.5	122.5	202	96
9.0	38.11	0	0	0	0	0					295.5	183	220	290	107.5	125	198	95
10.0	38.0	0	0.9	0	2.5	0	315	307	192	285	295.5	187	220	289	110.5	132	200.5	93
10.1									204									
10.13									273									
10.17									212									
10.3									200									
10.345									245									
10.38									227									
10.41									269.5									
10.45									203									
11.0	37.3	0	1.1	0	0	0					295	192.5	224	289	115	139.5	199	93.5
12.0	37.0	2	1.4	0	3.5	1	316	307.5	200	286	296	194.5	226	289.5	119.5	150	196	95.5
13.0	36.0	3	1.8	4	5.0	2.7			198		295.5	194	229	289.5	120	148	206	96.5
14.0	36.1	3	2.0	2.5	4.5	2.7	316	307	192	284	295.5	207	230	288	139.5	147.5	196	103
14.5									187.5									
14.75									306									
15.0	37.0	2.5	1.4	0	0	0					296	192.5	225	289	137	141	197.5	103
16.0	33.8	3.5	2.49	5	6	4	315.5	308	303.5	286	296	201	241	290	132	157.5	193	104.5
17.0	36.0	3	1.9	3	2.5	2.8					294	203	231	287	137	145	189.5	108
18.0	31.0	3.5	2.5	4	3.5	3.5	317	308	306	284	296	183	259	290	125	160	198	110.5
19.0	32.5	3	2.1	3	3.5	2.5					295	192	250	287	134	159	192	103
20.0	34.0	2.5	2.05	3.5	2.6	3.0	314	306	305	280	290.5	191	240	284	148	153.5	200	120
21.0	33.0	3	2.0	3	3.5	2.4					294	207.5	251	287	147	157	198	114.5
22.0	32.5	5.3	2.5	4.5	4	3.0	315	306	305	283	293	206	250	286	144	165	196	111
Valve Reopened																		
23.0	31.0	4.9	2.5	3.5	3	4.0					295	197	259	289	128	163.5	197.5	116
23.52												269						
23.98												207						
24.0	24.5	4	2.45	2.5	3	3.0	308	299	296	260.5	270	268	222	261	158	165	180	120
24.1														241				
25.0	24.5	0	1.8	0	0	1.25					269	235	237.5	229	146	153	179	115
26.0	27.0	9	6.6	10	9	8	310	300.5	299	264.5	274	225	225	221	149.5	157.5	186	112
27.0	30.5	10	7.1	12	9.5	7.8					280	229	202	192	137.5	149	172	114
28.0	32.0	12	8.0	10	12.3	9	311	301	301	271	282	236	179	187	135	146.6	179.5	115

TABLE 12

Data From Coolant Shutoff Tests on Simulated Shell-Tube Configurations. Test No. 9.03

THERMOCOUPLE LOCATIONS



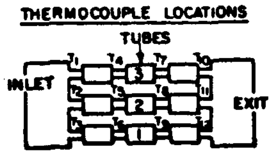
Conditions:
1. Cooling arrangement across tubes
2. No orifices
3. Tube axes horizontal, tubes stacked in vertical plane
4. Condensing steam flow rate per tube prior to shutoff = 0.022 lb/sec
5. Cooling flow rate per tube prior to shutoff = 0.81 lb/sec
6. Cooling sections nearest exit header shut off
7. Large inlet header

Time (seconds)	Mean Pressure Level (psig)	Magnitude of Pressure Oscillations (psi) Inlet Manifold	Exit Manifold	Tube 1 Exit	Tube 2 Exit	Tube 3 Exit	Mean Temperature Levels (°F) T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
0	35.3	3.7	2.3	4.0	3.5	3.2	310	306	304	282	287	197	167	186	109	123	160	92
1.0	35.8	10.0	6.9	9.0	9.0	7.0												
2.0	35.7	8.2	6.0	6.0	12.0	7.0												
Valve Closed																		
3.0	35.3	8.0	5.9	8.0	11.0	7.0	310	304	301	291	284	194	160	134	111	126	170	98
4.0	34.0	8.4	4.9	7.0	7.8	7.0												
5.0	34.5	5.6	6.4	9.0	9.0	8.0												
6.0	36.0	8.6	5.2	10.0	10.0	7.5	310	304	302	294	290	196	169	197	113	127	169	100
7.0	36.3	8.5	4.0	9.0	8.4	7.5												
8.0	35.2	10.0	7.0	7.0	8.0	7.0												
9.0	34.5	9.0	5.5	7.0	7.1	7.0	310	304	301	290	290	188	189	197	109	130	175	102
10.0	35.5	7.8	4.8	7.0	7.0	6.0												
11.0	35.1	6.4	4.2	4.8	4.1	4.8												
12.0	35.9	8.2	5.0	9.0	9.3	7.0	310	304	301	292	290	194	170	198	113	141	171	106
13.0	35.9	8.6	5.0	7.0	7.0	7.0												
14.0	35.0	6.3	5.0	5.5	6.8	6.1												
15.0	35.5	8.1	5.0	7.2	8.1	6.0	310	304	301	281	299	201	169	198	110	138	180	109
16.0	36.0	10.0	6.0	7.0	8.0	7.0												
17.0	35.0	9.0	6.0	7.0	4.1	7.0												
18.0	35.5	8.0	6.0	8.0	7.0	7.0	310	304	301	292	290	201	170	195	100	148	172	110
19.0	35.9	6.0	5.3	6.0	7.5	4.5												
20.0	36.2	10.5	6.3	8.0	7.4	8.0												
21.0	36.1	5.0	3.8	4.0	4.0	4.0	310	306	303	284	286	191	171	197	111	149	179	110
22.0	36.5	10.0	10.6	6.0	9.0	7.5												
23.0	37.0	7.5	5.2	7.0	6.5	8.0												
Valve Reopened																		
24.0	34.5	8.1	5.6	7.5	6.6	5.5	310	304	302	280	299	190	169	200	109	149	186	109
25.0	35.5	8.9	5.7	6.0	10.0	7.0												
26.0	33.0	7.0	3.0	5.5	4.8	5.0												
27.0	35.0	8.0	5.2	7.0	6.2	7.0	308	304	302	289	290	200	168	198	111	149	182	109
28.0	36.0	7.7	5.4	7.0	6.5	7.0												
29.0	36.0	6.5	4.3	6.0	5.0	4.9												
30.0	36.0	8.4	6.4	8.0	9.0	7.0	310	306	301	290	286	201	165	188	111	127	161	109

TABLE 13

Data From Coolant Shutoff Tests on Simulated Shell-Tube Configurations. Test No. 9.04

THERMOCOUPLE LOCATIONS



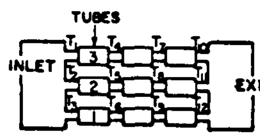
Conditions:
1. Cooling arrangement across tubes
2. Orifices in tube exits
3. Tube axes horizontal, tubes stacked in vertical plane
4. Condensing steam flow rate per tube prior to shutoff = 0.022 lb/sec
5. Cooling flow rate per tube prior to shutoff = 0.81 lb/sec
6. Cooling sections nearest inlet header shut off
7. Large inlet header

Time (seconds)	Mean Pressure Level (psig)	Magnitude of Pressure Oscillations (psi)					Mean Temperature Levels °F											
		Inlet Manifold	Exit Manifold	Tube 1 Exit	Tube 2 Exit	Tube 3 Exit	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
0	33.6	8.3	5.3	3.6	4.9	2.3	293	290	291	298	287	289	141	197.5	144	128	161	119
1.0	32.6	8.0	5.4	4.0	4.7	4.0												
2.0	41.0	6.5	4.5	2.9	5.3	4.0	306	302	301	307	301	300	137	198.5	144	124	162	122
Valve Closed																		
3.0	44.0	8.0	5.6	4.9	9.0	4.7												
4.0	42.5	3.8	3.0	4.0	4.9	3.0												
4.3														242				
4.4														250				
4.58														248				
4.62														264				
4.77														254				
4.8														294				
5.0	41.5	5.7	3.0	2.0	4.0	2.6	306	303	302	308	302	302	165	261	162	131	163	126
5.05														260				
5.1														297				
5.14														292				
5.2														298				
6.0	41.5	0	1.5	0	0	0												
7.0	39.0	0	1.0	0	1.0	0												
8.0	38.0	0	.5	0	0	0	302	299	298	304	298	298	185	293	187	128	188	148
9.0	37.0	0	.8	0	0	0												
10.0	37.3	0	.8	1.8	0	0												
11.0	35.0	0	.9	1.0	2.0	1.0	299	294	294	300	292	292	197	289	186	14[illegible]	190	150
12.0	35.8	1.0	1.0	1.5	2.0	1.0												
13.0	35.5	0	.6	0	0	0												
14.0	34.5	1.0	1.0	1.0	1.8	1.0	297	292	293	299	290	291	195	289	191	14[illegible]	188	155
15.0	34.0	0	1.1	0	0	0												
16.0	35.0	0	1.0	1.0	0	1.0												
17.0	34.0	0	1.2	0	0	0	299	292	294	299	290	290	202	288	187	143	193	155
18.0	33.1	0	.8	0	0	0												
19.0	33.0	0	1.2	0	0	0												
20.0	34.0	0	1.1	0	0	0	294	291	293	297	289	289	205	287	188	141	189	154
21.0	34.0	0	1.0	0	0	0												
22.0	34.0	0	1.0	0	0	0												
23.0	33.5	0	1.1	0	0	0	294	291	290	297	289	289	211	287	191	144	194	156
24.0	32.8	0	1.2	0	0	0												
Valve Reopened																		
25.0	21.0	0	1.3	0	0	0												
26.0	19.0	2.9	2.6	1.8	2.6	4.0	267	278	273	266	261	260	189	259	185	151	195	136
26.9														241				
26.95														259				
27.0	19.5	0	2.1	1.9	2.8	2.0												
27.1														234				
27.3														230				
27.34														256				
27.4														236				
28.0	20.5	6.2	4.4	4.4	7.6	2.9	284	283	281	269	262	261	162	233	174	131	177	131

TABLE 14

Data From Coolant Shutoff Tests on Simulated Shell-Tube Configurations. Test No. 9.05

THERMOCOUPLE LOCATIONS



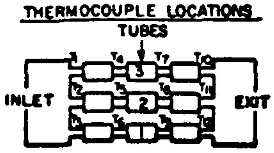
Conditions:
1. Cooling arrangement across tubes
2. Orifices in tube exits
3. Tube axes horizontal, tubes stacked in vertical plane
4. Condensing steam flow rate per tube prior to shutoff = 0.022 lb/sec
5. Cooling flow rate per tube prior to shutoff = 0.81 lb/sec
6. Cooling sections shut off - middle
7. Large inlet header

Time (seconds)	Mean Pressure Level (psig)	Magnitude of Pressure Oscillations (psi): Inlet Manifold	Exit Manifold	Tube 1 Exit	Tube 2 Exit	Tube 3 Exit	Mean Temperature Levels (°F): T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
0	33.0	6.5	5.1	6.0	5.3	4.0	291	287	289	294	288	287	141	197	145	122	164	121
1.0	33.0	6.9	4.7	7.0	4.0	4.0												
2.0	32.5	3.0	2.1	2.4	3.0	2.2												
Valve Closed																		
3.0	34.5	5.0	2.2	6.5	3.0	11.0	297	292	295	299	292	291	140	202	139	122	157	122
4.0	36.6	8.4	1.0	4.3	3.0	5.0												
5.0	37.0	7.1	0.4	6.1	3.1	4.0	300	296	296	301	295	294	149	272	145	121	156	123
6.0	36.5	7.0	0.7	5.1	3.0	4.0												
7.0	37.0	5.4	0.3	4.0	3.1	3.8												
8.0	36.8	3.0	1.7	4.0	2.0	3.0	300	296	297	301	295	295	172	290	174	124	198	126
9.0	36.8	3.9	1.8	2.8	2.6	3.0												
10.0	36.5	3.6	1.4	3.0	2.9	3.1												
11.0	36.1	3.1	1.0	2.5	1.8	2.6	298	293	294	300	292	292	181	289	191	132	197	133
12.0	35.0	4.3	2.1	2.0	2.9	3.1												
13.0	36.0	5.0	2.4	3.0	3.5	3.9												
14.0	36.5	3.0	2.1	2.2	3.0	2.5	299	293	294	300	294	294	200	289	208	148	199	150
15.0	36.0	2.9	1.8	2.1	3.0	2.9												
16.0	34.8	2.9	1.5	2.9	2.9	3.1												
17.0	36.0	3.0	3.0	2.2	4.3	2.6	298	293	295	301	294	291	217	289	219	155	196	147
18.0	35.5	6.2	3.0	2.7	5.0	3.9												
19.0	33.5	4.0	2.0	0	3.0	3.0												
20.0	36.5	4.1	2.5	2.0	3.2	2.1	298	294	294	300	293	293	230	290	224	148	194	163
21.0	36.0	5.9	2.0	4.0	2.9	3.5												
22.0	36.0	3.9	3.1	1.9	3.0	2.6												
23.0	33.8	3.4	1.6	1.8	3.9	2.2	294	291	292	297	290	290	247	287	228	167	195	159
24.0	33.0	4.0	2.0	2.0	3.0	2.4												
Valve Reopened																		
25.0	27.2	6.0	2.5	7.4	3.2	3.9												
25.54														267				
25.73														273				
25.77														252				
26.0	26.5	3.9	2.3	2.6	1.7	2.7	281	278	278	281	275	273	225	237	223	164	191	161
26.52																145		
26.8																150		
27.0	26.5	10.0	6.0	5.5	4.7	4.1												
27.2																158		
27.31																169		
27.54																160		
27.83																175		
28.0	26.5	5.8	4.0	4.6	6.8	5.0												
28.5																165		
28.66																152		
29.0	27.0	8.9	5.8	5.9	4.0	4.4	280	285	284	282	278	272	169	194	161	164	186	160
29.1																166		
30.0	28.0	7.8	5.0	4.8	6.5	4.1												
31.0	29.0	6.0	5.0	3.0	4.9	3.4												
32.0	30.0	7.6	5.0	4.9	7.1	4.1	289	286	289	290	284	282	143	194	143	145	168	139
33.0	31.0	3.8	2.1	2.6	2.0	1.8												
34.0	32.0	0	1.1	3.1	1.0	2.3	292	288	291	293	287	287	142	206	137	125	160	129

TABLE 15

Data From Coolant Shutoff Tests on Simulated Shell-Tube Configurations. Test No. 9.06

THERMOCOUPLE LOCATIONS



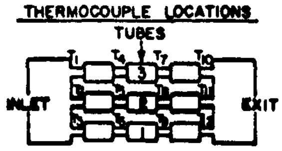
Conditions:
1. Cooling arrangement across tubes
2. Orifices in tube exits
3. Tube axes horizontal, tubes stacked in vertical plane
4. Condensing steam flow rate per tube prior to shutoff = 0.022 lb/sec
5. Cooling flow rate per tube prior to shutoff = 0.81 lb/sec
6. Cooling section nearest exit shut off
7. Large inlet header

Time (seconds)	Mean Pressure Level (psig)	Magnitude of Pressure Oscillations (psi): Inlet Manifold	Exit Manifold	Tube 1 Exit	Tube 2 Exit	Tube 3 Exit	Mean Temperature Levels (°F): T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
0	33.0	2.8	2.3	4.2	1.9	2.1	292	290	290	296	289	289	139	201	140	122	150	122
1.0	33.0	2.0	1.8	0	0	1.0												
2.0	32.0	2.1	1.6	3.1	1.6	2.3												
Valve Closed																		
3.0	33.0	2.3	2.5	2.7	2.2	2.8	292	288	290	295	298	288	139	201	140	129	161	120
4.0	33.0	2.0	1.6	1.9	2.9	2.1												
5.0	33.0	0	1.3	0	0	1.2												
6.0	33.0	6.4	3.2	2.7	3.9	4.6	292	289	290	296	289	287	138	202	143	128	170	119
7.0	32.8	3.4	1.9	1.3	3.9	2.9												
8.0	32.8	3.0	3.1	2.0	1.5	2.1												
9.0	33.0	3.1	2.9	4.6	2.0	3.0	292	289	290	294	289	288	138	202	138	135	171	125
10.0	32.8	1.6	1.5	0	2.3	1.6												
11.0	32.4	6.0	3.0	2.1	3.4	3.6												
12.0	32.0	6.0	4.2	6.0	6.2	3.9	290	289	289	294	288	280	140	199	142	145	178	128
13.0	33.0	6.8	4.8	5.4	4.8	3.1												
14.0	33.0	4.2	1.9	2.0	2.7	2.4												
15.0	31.5	6.0	4.4	2.4	5.3	2.8	290	286	287	291	284	283	144	195	142	147	179	130
16.0	31.5	7.1	4.4	3.1	6.0	3.9												
17.0	32.0	7.2	5.5	4.3	4.4	3.5												
18.0	32.5	3.8	2.4	2.2	2.0	2.8	290	287	289	293	290	279	141	200	142	146	177	138
19.0	34.0	3.0	1.3	2.0	1.9	2.5												
20.0	34.0	4.2	2.4	2.5	2.4	2.1												
21.0	32.5	3.3	2.9	2.8	1.9	3.0	290	287	289	293	287	284	138	200	142	150	181	135
22.0	32.5	6.8	4.3	4.0	3.8	4.0												
23.0	33.0	4.9	2.5	1.5	2.5	2.9												
24.0	33.5	2.0	0.8	1.0	0.9	1.2	292	290	291	296	289	289	139	200	139	152	186	138
Valve Reopened																		
25.0	32.8	2.6	2.3	2.0	1.5	2.0												
26.0	32.0	6.0	4.0	4.0	8.0	3.5												
27.0	31.0	6.0	4.3	4.0	7.0	4.0	288	280	285	290	277	281	137	195	137	155	183	135
28.0	31.5	8.4	5.6	5.0	7.2	5.0												
29.0	31.9	7.0	4.0	6.9	4.0	4.5												
30.0	34.0	7.5	7.2	4.6	3.4	3.3												
31.0	33.0	6.4	2.7	2.3	3.0	4.2	292	290	290	297	289	282	134	190	136	138	150	124
32.0	33.0	10.5	5.8	6.5	10.0	6.0												
33.0	33.1	7.0	3.9	5.0	7.0	4.0												
34.0	33.0	5.0	2.7	2.0	3.0	3.1	292	290	290	297	289	285	135	192	140	128	158	118

TABLE 16

Data From Coolant Shutoff Tests on Simulated Shell-Tube Configurations. Test No. 9.07

THERMOCOUPLE LOCATIONS



Conditions:
1. Cooling arrangement across tubes
2. No orifices
3. Tube axes horizontal, tubes stacked in horizontal plane
4. Condensing steam flow rate per tube prior to shutoff = 0.021 lb/sec
5. Cooling flow rate per tube prior to shutoff = 0.81 lb/sec
6. Cooling sections shut off - nearest inlet header
7. Large inlet header

Time (seconds)	Mean Pressure Level (psig)	Magnitude of Pressure Oscillations (psi): Inlet Manifold	Exit Manifold	Tube 1 Exit	Tube 2 Exit	Tube 3 Exit	Mean Temperature Levels - °F: T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
0	40.5	10	6.7	11.0	6.0	9.5	309	303	303	296	293	246	177	196	135	124	153	100
1.0	40.4	10.5	6.0	3.0	14.5	9.5												
2.0	42.5	12.5	7.9	11.5	8.0	12.0	309	302	302	301	297	245	179	194	137	123	162	98
Valve Closed																		
2.25												250						
2.29												287						
2.35												266						
2.50												264						
2.55												306						
2.70												311						
3.0	52.8	13.0	8.1	13.0	14.0	12.5												
3.9														205				
4.0	53.5	12.0	8.2	13.5	9.0	11.0	325	315	317	317	314	315	182	216	142	126	157	120
4.075														229				
4.1														294				
4.125														303				
4.15														291				
4.163														270				
4.265														238				
4.895														246				
4.935														298				
4.965														293				
5.0	52.3	12.0	7.9	12.0	10.0	11.5								266			151	
5.115														263				
5.17														304				
5.65																	167	
6.0	51.0	2.0	2.5	3.0	1.0	1.0	321	310	312	314	310	312	195	304	144	120	158	116
7.0	49.0	2.0	0.3	3.0	1.0	1.0							213					
8.0	47.1	2.0	0.4	2.0	1.0	1.0	314	305	306	306	304	305	218	297	181	129	190	115
8.7		2.0		2.0	1.0	1.0										145		
9.0	45.7	2.0	1.0	2.0	1.0	1.0							223					
9.4		2.0		2.0	1.0	1.0										134		
9.45		2.0		2.0	1.0	1.0							214					
9.6		2.0		2.0	1.0	1.0											200	
10.0	46.3	2.0	0	2.0	1.0	1.0	312	302	301	303	299	301	224	294	182	143	190	113
11.0	44.5	2.0	0	2.0	1.0	1.0							216					
11.5		2.0		2.0		1.0							226					
12.0	42.5	2.0	0	2.0	3.0	1.0	306	299	300	301	297	300	218	290	181	149	197	116
13.0	42.0	2.0	1.0	2.0	3.0	1.0												
14.0	41.2	2.0	1.0	2.0	3.0	1.0	300	300	302	297	294	296	221	287	183	151	185	119
14.93		2.0		2.0	3.0	1.0											137	
15.0	43.0	2.0	1.5	2.0	3.0	1.0							217					
15.05		2.0		2.0	3.0	1.0											196	
15.4		2.0		2.0	3.0	1.0							214					
15.5		2.0		2.0	3.0	1.0											186	
16.0	41.3	2.0	1.5	2.0	3.0	1.0	306	303	302	298	294	296	219	290	187	154	189	113
17.0	39.0	2.0	1.5	2.0	3.0	1.0									179			
17.02		2.0		2.0	3.0	1.0									178			
17.06		2.0		2.0	3.0	1.0									154			
17.155		2.0		2.0	3.0	1.0									161			
17.6		2.0		2.0	3.0	1.0									175			
18.0	41.0	2.0	1.0	2.0	3.0	1.0	312	304	303	296	293	295	220	287	174	149	183	118
19.0	42.0	2.0	1.0	2.0	3.0	2.0									198		198	
20.0	42.0	2.0	1.5	2.0	3.0	2.0	311	304	303	299	296	297	218	289	174	150	188	117
21.0	39.3	2.0	1.0	2.0	3.0	2.0												

TABLE 16 (Cont'd.)

Time (seconds)	Mean Pressure Level (psig)	Magnitude of Pressure Oscillations (psi): Inlet Manifold	Exit Manifold	Tube 1 Exit	Tube 2 Exit	Tube 3 Exit	Mean Temperature Levels (°F): T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
21.25		2.0		2.0	3.0	2.0											173	
21.8		2.0		2.0	3.0	2.0												112
21.9		2.0		2.0	3.0	2.0											194	104
22.0	40.5	2.0	1.0	2.0	3.0	2.0	310	303	302	297	292	298	216	286	191	150	190	105
22.2		2.0		2.0	3.0	2.0											195	119
22.6		2.0		2.0	3.0	2.0											183	
23.0	42.3	2.0	1.5	2.0	3.0	2.0											192	
24.0	42.5	2.0	1.5	2.0	3.0	2.0	311	304	303	300	295	300	213	289	180	148	184	117
25.0	42.5	2.0	1.0	2.0	3.0	2.0												
26.0	40.7	2.0	1.0	2.0	3.0	2.0	310	303	302	297	293	299	217	287	179	146	193	115
26.8		2.0		2.0	3.0								226					
27.0	41.4	2.0	0	2.0	3.0	5.5												
27.37		2.0		2.0	3.0								217					
27.6		2.0		2.0	3.0											156		
27.7		2.0		2.0	3.0												188	
27.83		2.0		2.0	3.0								231					
27.85		2.0		2.0	3.0													129
27.9		2.0		2.0	3.0												175	114
28.0	41.0	2.0	0	2.0	3.0	2.0	310	303	302	296	292	299	222	288	181	150	179	114
28.1		2.0		2.0	3.0											144		
29.0	41.0	2.0	0	2.0	3.0	2.0						300	210	289	179	143		
	Valve Reopened																	
29.28															173			
29.34															179			
29.4															168		196	
29.46											274							
29.52											275							
29.58											271						190	
29.59													233					
29.6										275		273		266				
29.65													222				155	
29.67													257					
29.695													265					
29.7										277	277	275		272	173	161		
29.75															156			
29.8										269			230	260				
29.82											266							
29.9										269	270		219	264				
29.95													205	257		145		
30.0	24.8	8.0	3.9	6.0	7.0	5.5	301	294	292	264	252	263	205	245	160	145	168	120
30.06											263							
30.08												259						
30.1											262							
30.17											252							
30.2												256						
30.3										264			198		182			
30.31												262						
30.33															167			
30.35													187					
30.4										256								110
30.43												252						
30.5								287		261								121
30.52												256						
30.6										254		251						
30.7																		
30.71												260						
30.8																		
30.82												252						
30.9										263								
30.93												261						
31.0	23.3	7.0	5.0	4.0	5.0	5.5		281		261		257		248	168			

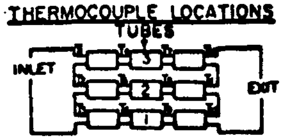
TABLE 16 (Cont'd.)

Time (seconds)	Mean Pressure Level (psig)	Magnitude of Pressure Oscillations (psi) Inlet Manifold	Exit Manifold	Tube 1 Exit	Tube 2 Exit	Tube 3 Exit	Mean Temperature Levels (°F) T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
31.06												254						
31.1										258								
31.2										252		261						
31.3										258								
31.4										261								
31.5								282		260								
31.6										259								
31.7										264								
31.8										259								
31.9										265								
32.0	25.5	1.0	2.0	4.0	3.0	3.5	299	286	291	263	258	260	188	251	162	132	170	120
32.2																		125
32.5								290		266								
32.6																		113
33.0	27.5	1.0	2.0	2.0	2.0	2.0		294		271								120
34.0	30.7	5.5	3.0	5.5	5.0	6.0	304	295	295	275	275	272	183	235	154	127	164	106
34.45																		116
34.63																		104
34.67										272								
34.8										280								
34.9										276								
35.0	32.5	8.5	4.7	7.0	8.0	7.0				281								119
35.1										282								
36.0	34.5	9.5	5.8	8.0	8.0	5.0	306	297	297	284	285	281	173	195	123	131	170	115
36.2																	165	
36.38																	188	
36.6																	175	
37.0	37.2	10.5	5.6	8.5	10.0	7.0												
37.7																	161	
38.0	38.1	10.0	6.5	6.0	16.0	8.0											167	111
38.4																		123
39.0	38.9	12.0	6.3	6.9	17.0	7.0	302	306	297	293	290	290	175	191	120	128	164	103

TABLE 17

Data From Coolant Shutoff Tests on Simulated Shell-Tube Configurations. Test No. 9.08

THERMOCOUPLE LOCATIONS



Conditions:

1. Cooling arrangement across tubes
2. No orifices
3. Tube axes horizontal, tubes stacked in horizontal plane
4. Condensing steam flow rate per tube prior to shutoff = 0.021 lb/sec.
5. Cooling flow rate per tube prior to shutoff = 0.81 lb/sec.
6. Cooling sections shut off - middle
7. Large inlet header

Time (seconds)	Mean Pressure Level (psig)	Magnitude of Pressure Oscillations (psi): Inlet Manifold	Exit Manifold	Tube 1 Exit	Tube 2 Exit	Tube 3 Exit	Mean Temperature Levels (°F): T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
0	40.0	11.0	7.5	11.0	11.0	10.0	300	300.9	291	298	294	281	175	196	135	126	157	107
1	41.0	9.5	5.5	8.5	13.0	8.5												
1.75												290						
2.0	39.0	11.5	7.6	10.0	12.5	12.0	301.5	297.5	295	295	294	253	180	204	134	130	160	109.5
Valve closed																		
2.3														211				
2.35														223				
2.37														262				
2.43														238				
2.565														240				
2.7														289.5				
3.0	42.9	3.0	0	7.0	4.9	3.5						236						
4.0	43.0	7.0	3.0	19.0	6.1	6.0	308	299	300.5	300	300	240	189	291	125	127	161	103
5.0	43.5	5.5	2.0	14.0	7.5	4.9						197						
6.0	43.0	5.5	2.5	12.0	6.9	6.0	310	299	300.5	300.5	300	196	214	290.5	116	127.5	188	89
7.0	42.6	5.0	3.1	12.7	5.5	6.0												
8.0	44.0	4.9	3.0	15.0	6.0	6.1	307.5	299.5	301	300	300	198	232	292	124	149.5	196	86
9.0	42.6	6.5	3.6	12.6	7.1	6.0												
10.0	43.3	3.0	2.0	5.1	2.5	3.5	309	298	300	300	299	223	240	290	140	137.5	190	92
11.0	44.0	4.0	3.5	9.5	4.9	3.5												
12.0	43.3	9.5	7.0	12.0	10.0	9.5	305.5	298	300	299	299.5	218	232	290	148	155	190	102.5
12.23												218						
12.3												294						
13.0	43.1	2.5	1.0	3.0	2.5	2.55												
14.0	43.2	3.0	1.0	3.0	3.0	3.5	307.5	299	300	300	300	299	218	290.5	171	143	197	104
15.0	43.3	0	1.0	2.5	1.5	3.0												
16.0	43.5	0	1.0	4.0	0	0	309.5	299	300	301	299.5	300	240	291	170	150	200	106
17.0	44.0	0	2.5	2.5	2.3	2.0												
18.0	46.0	0	1.5	3.0	0	0	311	301	303	303	301	290	253	295	180	163	201	109
19.0	45.6	0	2.5	2.8	0	0											201	
19.25												300						
19.35												267						
19.65													270					
19.85												265						
19.9												294						
20.0	42.0	5.0	6.5	6.0	6.5	5.0	303	295	291	297	296		258	288	177	167		113.5
20.1												298						
20.2												270.2	243				206	
20.3												296						
20.4																	151	
20.5													260.1					
20.8													217				180	
21.0	41.4	8.0	7.0	6.0	7.3	5.5												
22.0	42.5	0	0	0	0	0	307.5	295.5	299	299.5	298	298	257.5	290	179.5	149.5	189	123
23.0	42.5	0	1.0	0	0	0											201	
24.0	40.0	8.0	4.3	5.0	7.0	5.0	299.5	290.5	291	293	292	290	254	285	212	155	190	124
25.0	40.0	10.0	5.0	10.0	8.9	7.5												
26.0	40.0	10.4	5.0	10.0	10.5	8.5	300.5	294.5	293	291	293	290	243	286	206	160	186	122.5
27.0	40.18	7.0	3.6	7.0	7.7	5.11												
28.0	40.5	5.0	2.4	4.0	7.3	4.5	300	299	291	294	292	290	248	285	215	155	187.5	124
29.0	41.0	8.0	3.0	4.0	8.0	6.5												
30.0	40.7	8.5	4.5	6.5	8.0	6.5	301	299.5	296	295.5	295	294	262	289	213	169	182	130

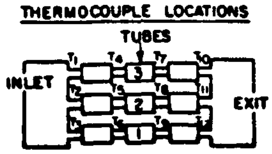
TABLE 17 (Cont'd.)

Time (seconds)	Mean Pressure Level (psig)	Magnitude of Pressure Oscillations (psi) Inlet Manifold	Exit Manifold	Tube 1 Exit	Tube 2 Exit	Tube 3 Exit	Mean Temperature Levels (°F) T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
Valve Reopened																		
30.6														251				
31.0	29.0	7.8	4.7	7.3	7.0	6.0								267.5				
32.0	29.0	7.3	4.1	6.0	7.5	5.5	297.5	274	277	273.5	273	270	250	237	201	156	169	135
33.0	33.0	8.0	4.9	10.5	12.5	8.0												
34.0	33.5	12.5	6.4	10.5	13.5	10.0	300	289	288	279	280	277	190	198	154	150.5	169	147.5
35.0	34.5	11.0	6.1	11.0	13.5	10.5												
36.0	36.5	10.5	6.7	11.0	17.5	10.0	305	294	293.5	287.5	287.5	283	172	187	141	152	165	139
37.0	37.5	11.0	6.6	11.5	17.3	10.0												
38.0	37.1	8.0	5.3	9.5	11.25	8.9	306	295	297	290	290	288	170	188	133	149	159	127

TABLE 12

Data From Coolant Shutoff Tests on Simulated Shell-Tube Configurations. Test No. 9.09

THERMOCOUPLE LOCATIONS



Conditions:

1. Cooling arrangement across tubes
2. No orifices
3. Tube axes horizontal, tubes stacked in horizontal plane
4. Condensing steam flow rate per tube prior to shutoff = 0.021 lb/sec
5. Cooling flow rate per tube prior to shutoff = 0.81 lb/sec
6. Cooling sections shut off - nearest exit header
7. Large inlet header

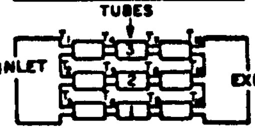
Time (seconds)	Mean Pressure Level (psig)	Magnitude of Pressure Oscillations (psi): Inlet Manifold	Exit Manifold	Tube 1 Exit	Tube 2 Exit	Tube 3 Exit	Mean Temperature Levels (°F): T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
0	42.0	9.0	6.4	9.0	13.0	12.0	303	298	299	294	289	293	168	193	133	125	155	98
1	40.0	7.5	7.0	9.0	10.0	8.5												
2	40.5	10.5	8.0	5.0	15.0	11.0	304	298	297	293	289	291	176	193	125	124	154	98
Valve Closed																		
3	41.0	11.0	6.8	9.0	11.5	7.0												
4	41.5	9.0	5.6	8.0	13.0	9.0	304	297	298	294	291	292	173	187	132	125	155	101
5	41.0	7.0	7.7	8.0	10.5	7.5												
6	40.0	6.0	7.5	7.0	10.0	7.0	304	298	299	297	292	294	173	196	137	128	166	114
7	40.5	7.0	5.7	7.0	14.0	7.0												
8	40.5	8.0	5.4	6.0	12.0	8.0	304	298	299	295	285	293	173	197	137	134	172	114
9	41.5	8.0	6.0	9.0	14.0	8.0												
10	40.5	8.0	5.0	8.0	11.0	7.5	302	298	297	293	290	290	176	194	132	139	173	115
11	40.7	9.0	6.9	10.0	12.0	7.5												
12	40.5	8.0	6.2	8.0	10.0	6.0	305	298	299	296	293	291	179	195	143	138	175	120
13	40.5	9.0	6.0	9.0	12.0	7.5												
14	40.0	5.0	7.6	6.0	8.5	5.0	306	297	297	294	290	289	171	196	137	145	175	119
14.75												288						
14.78												266						
14.9												264						
15	40.5	9.0	7.0	10.0	13.0	8.5						291						
16	40.5	5.0	5.2	6.0	10.0	6.0	304	298	297	295	291	293	174	193	135	142	176	116
17	40.7	12.0	6.6	11.0	13.0	11.0												
18	40.5	7.0	6.1	8.0	10.0	6.5	304	299	298	295	292	292	175	192	133	143	175	121
19	39.9	9.0	6.1	8.0	13.0	8.7												
19.95												288						
20	39.9	7.5	6.0	9.0	9.0	7.0	304	298	298	295	290	267	180	196	138	148	175	125
20.09												260						
20.15												288						
21	40.7	11.0	7.2	10.0	12.0	9.0												
22	40.5	8.0	6.4	8.0	10.0	6.5	304	299	300	295	294	290	174	183	139	144	177	122
23	40.5	9.5	6.5	11.0	9.0	8.0												
24	40.5	12.0	6.9	10.0	8.0	7.0	306	299	299	296	291	293	179	193	129	148	182	127
25	40.5	8.0	5.2	8.0	12.0	6.5												
26	40.6	9.0	7.6	11.0	16.0	11.0	306	298	299	295	289	280	175	195	134	146	180	130
27	40.6	12.0	6.0	9.0	14.0	8.5												
28	40.8	10.0	5.7	6.0	10.0	5.5	307	299	298	297	294	295	175	195	130	142	179	125
29	40.8	11.0	5.5	10.0	13.0	9.0												
30	40.8	10.5	6.2	9.0	11.0	8.0	306	298	297	294	287	277	179	194	137	149	180	131
Valve Reopened																		
31	40.0	11.0	6.9	9.0	11.0	7.0												
32	39.3	10.0	6.1	6.0	11.0	8.5	305	297	296	290	286	287	175	194	123	145	185	125
33	40.5	10.5	5.8	8.0	11.0	7.0												
34	39.1	10.0	6.4	10.0	12.0	8.0												
35	40.5	10.5	6.0	7.0	10.0	7.0	306	297	299	294	291	293	174	196	134	137	159	119

TABLE 19

Data From Coolant Shutoff Tests on Simulated Shell-Tube Configurations. Test No. 9.10

THERMOCOUPLE LOCATIONS

TUBES



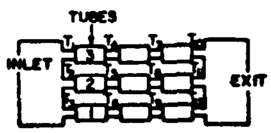
Conditions:
1. Cooling arrangement across tubes
2. Orifices in tube exits
3. Tube axes horizontal,tubes stacked in horizontal plane
4. Condensing steam flow rate per tube prior to shutoff = 0.021 lb/sec
5. Cooling flow rate per tube prior to shutoff = 0.81 lb/sec
6. Cooling sections nearest inlet header shut off
7. Large inlet header

Time	Mean Pressure Level	Magnitude of Pressure Oscillations (psi)					Mean Temperature Levels (°F)											
(seconds)	(psig)	Inlet Manifold	Exit Manifold	Tube 1 Exit	Tube 2 Exit	Tube 3 Exit	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
0	39.7	7.5	4.2	4.5	8.0	6.5	298	299.5	298	293	292.5	290.5	189		141	122.5	158	111.5
1.0	39.7	5.1	3.4	5.0	8.0	5.0												
2.0	50.5	7.5	5.7	9.6	18.5	6.5	320	309	312	310.5	310	310	190	202	143	127.5	160	100
Valve Closed																		
3.0	52.4	9.5	5.95	9.6	19.0	7.0								214				
3.715														239				
3.77														298				
3.83														272				
4.0	56.0	5.0	3.5	5.6	7.0	4.0	322.5	311.5	314	313	312.5	312	198	253	152.5	137	160	115
4.04														290				
4.24														303				
4.315														270				
4.4														303				
5.0	51.5	2.5	0.9	2.5	3.2	2.3												
6.0	49.4	2.5	1.1	0	3.0	1.5	319	308	310	309.5	308.5	309	211	300	189	140	168	120
7.0	58.4	0	0.45	0	1.6	0												
8.0	47.5	0	0.80	0	1.0	1.5	314	304	307	307	304.5	305	220	298	192	152	197	116
9.0	46.7	0	0.75	0	0	0												
10.0	46.0	0	0.6	0	0	0	310.5	301	304	303	301.5	302	240	295	204	160	203	123
11.0	44.0	0	.35	0	2.3	0												
12.0	43.3	0	0	0	2.5	0	308	299	300	300	299	299.5	249.5	291	205	164.5	192.5	129
13.0	42.4	0	0	0	0	0												
14.0	42.4	0	0	0	0	0	306	297	299	299	296	297.5	283	290	204	173	202	131
15.0	42.0	2.0	0	0	2.5	0												
16.0	41.5	2.3	0.95	0	2.7	0	304	296	297	296	293	294	289	289	204	175	195	130.5
17.0	41.7	2.3	0.7	0	2.5	1.25												
18.0	41.0	2.6	1.3	1.8	3.1	1.4	303	295	295	295	293	293	287.5	288	203	170	194	131
19.0	40.0	3.0	2.05	2.5	4.5	2.5				291	290							
Valve Reopened																		
20.0	23.0	2.5	1.95	1.8	2.3	1.5	295	287.5	288	260	259	255	250	253	194	164	181	133
21.0	24.9	6.0	3.6	5.3	5.0	4.0												
22.0	23.9	4.0	2.2	2.8	3.0	4.0	296	284	288	263	260	259.5	222	248	180	149	174.5	130.5
23.0	27.3	5.0	4.1	4.6	6.125	4.0												
24.0	29.0	7.0	3.75	4.9	8.1	4.9	299	283	290	273	273	270	175	216	148	139	168	129
25.0	32.0	7.0	4.1	5.0	7.2	3.95	300	290	292	301	279.5	275	168	199	143	142	174	128

TABLE 20

Data From Coolant Shutoff Tests on Simulated Shell-Tube Configurations. Test No. 9.11

THERMOCOUPLE LOCATIONS



Conditions:

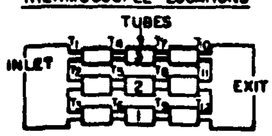
1. Cooling arrangement across tubes
2. Orifices in tube exits
3. Tube axes horizontal, tubes stacked in horizontal plane
4. Condensing steam flow rate per tube prior to shutoff = 0.021 lb/sec
5. Cooling flow rate per tube prior to shutoff = 0.81 lb/sec
6. Cooling sections shut off - middle
7. Large inlet header

Time (seconds)	Mean Pressure Level (psig)	Magnitude of Pressure Oscillations (psi) Inlet Manifold	Exit Manifold	Tube 1 Exit	Tube 2 Exit	Tube 3 Exit	Mean Temperature Levels (°F) T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
0	36.2	8.0	3.1	2.9	7.5	3.0	296	290	291	292	287	286	189	196	141	121	158	101
1	36.9	4.0	3.4	4.5	12.0	4.0												
2	36.0	5.0	3.5	5.0	7.5	4.0	299	290.5	292	295.5	290	290	188	195	144	130	159	113.5
Valve closed																		
3	39.8	3.0	3.4	3.0	6.5	2.4	304	298	297	300	296	297	187.5	209	141	131	155	101
4	39.9	3.0	2.5	2.0	2.5	0												
5	40.3	1.0	1.0	1.5	2.0	2.2												
6	39.8	0	.7	.9	2.5	2.0	304	298	297.5	301	298	298	210	282	148	131	170.5	99
6.075														284				
6.15														288				
6.2														281				
6.27														282				
6.29														280				
6.5														288				
6.6														275				
7	40.1	1.0	.9	.9	2.5	2.0								291				
8	39.6	2.0	1.0	1.0	2.0	1.9												
9	40.0	2.5	1.1	1.0	2.0	1.9	304.7	298	298	302	298	298	232	292	179	130.5	197	99
10	39.2	2.5	1.0	1.0	2.0	1.9												
11	39.2	2.2	1.0	1.5	2.2	2.0												
12	39.5	2.0	1.1	1.9	2.0	1.9												
13	39.2	2.5	1.2	2.0	2.4	2.0												
14	39.4	2.5	1.2	2.0	2.4	2.0	304	298	299	302	295	297	230	292	199	155	195	114
15	39.35	2.3	1.2	1.7	2.2	2.0												
16	39.0	2.0	1.2	1.5	2.0	2.0	303	296	297	300	295	294	239	290	204	155	191	121
17	38.0	2.5	1.4	1.4	2.2	1.5												
18	38.95	3.0	1.9	1.4	2.4	1.0	303	295	296	300	295	294	241	290	210	154	196	124
19	38.3	2.5	1.4	1.5	2.4	1.2												
20	38.6	2.0	1.0	1.5	2.4	1.5	303	294.5	296	300	295	294	248	290	214	161	200	131
21	36.6	2.0	1.0	1.5	2.4	1.5												
22	37.1	2.0	1.5	1.3	2.5	1.8												
23	37.5	2.5	1.7	1.4	2.8	1.7												
24	37.2	3.0	2.0	1.5	3.0	2.0												
25	36.75	3.0	2.0	1.5	3.0	2.0	299	292	293	297	290	291	249.5	287	225	160	201	133
26	36.9	2.7	1.6	.7	2.7	2.0												
27	38.0	2.4	1.1	0	2.5	2.0	303	294	293	299	294	293	243	290	230	152	146	132
28	38.2	3.0	1.3	1.0	3.0	2.2												
29	37.0	3.3	1.6	1.7	3.5	2.4	299	291	292	296	290	289	256	286	234	150	191	142
30	36.0	3.6	1.9	2.0	3.0	2.5												
30.5														281				
30.6														272				
30.7														277				
31	28.0	4.0	2.3	2.2	2.5	2.5	285	280	281	282	277	275	247	274	235	160	194	158
31.1														273				
31.15														261				
31.3														273				
31.49														261				
31.525														269				
31.6														242				
32	25.95	5.5	3.5	3.5	6.5	4.0												
Valve Reopened																		
33	26.5	7.5	4.8	5.0	9.0	5.5	291	283	272.5	276	271	267	231	217	201	164	187	145
34	27.5	5.0	4.0	4.0	10.0	4.0												
35	29.0	7.0	4.7	5.0	12.5	4.4	297	289	281	282	276	274	190.5	192	155	159	181	139

TABLE 21

Data From Coolant Shutoff Tests on Simulated Shell-Tube Configurations. Test No. 9.12

THERMOCOUPLE LOCATIONS



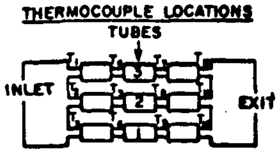
Conditions:
1. Cooling arrangement across tubes
2. Orifices in tube exits
3. Tube axes horizontal, tubes stacked in horizontal plane
4. Condensing steam flow rate per tube prior to shutoff = 0.031 lb/sec
5. Cooling flow rate per tube prior to shutoff = 0.81 lb/sec
6. Cooling sections nearest exit header shut off
7. Large inlet header

	Mean Pressure	Magnitude of Pressure Oscillations (psi)					Mean Temperature Levels (°F)											
Time (seconds)	Level (psig)	Inlet Manifold	Exit Manifold	Tube 1 Exit	Tube 2 Exit	Tube 3 Exit	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
0	36.4	5.9	4.9	7.0	5.3	4.0	293	283	289	292	280	285	189	180	144	126	158	102
1.0	36.3	8.5	6.0	4.0	14.0	6.0												
2.0	35.3	2.6	4.0	8.0	6.0	4.0	294	285	290	292	286	287	189	195	142	130	158	112
Valve Closed																		
3.0	35.9	7.2	5.0	4.5	7.2	4.5												
4.0	35.8	6.0	4.7	4.0	10.0	4.0	299	290	290.5	294	289	288	189	188	141	129	155	107
5.0	36.0	7.9	4.3	2.9	7.0	3.5												
6.0	35.5	4.2	3.6	1.9	6.0	3.0	298	291	290.5	294	290	288	187	187	140	132	161	110
7.0	35.4	6.0	3.4	3.0	5.2	3.5												
8.0	35.6	10.0	5.0	6.2	7.8	4.0	296	289	290	292	288	286	191	189	145	138	167	110
9.0	36.1	6.3	4.3	6.0	6.0	4.0												
10.0	35.7	8.0	6.0	5.0	6.0	3.5	295	289	290	292	289	285	186	198	143	141	169	116
11.0	35.8	5.0	4.0	3.0	5.6	3.4												
12.0	35.5	6.5	4.9	4.0	6.0	4.4	297	289	291	294	289	287	189	198	143	147	171	121
13.0	35.6	6.3	3.8	4.0	6.7	3.6												
14.0	36.0	7.0	4.7	4.1	6.8	4.8	298	290	292	295	290	289	187	198	142	146	177	132
15.0	35.9	7.6	4.3	4.0	8.9	4.5												
16.0	35.4	4.6	3.8	3.1	6.0	3.0	297	289	290	294	288	288	189	197	145	146	179	122
17.0	35.7	7.1	4.8	6.0	9.0	5.0												
18.0	36.2	6.2	4.0	4.0	9.0	5.0	298	291	292	294	290	289	193.5	198	139	150	179	129
19.0	36.2	4.9	3.6	4.0	6.0	3.5												
20.0	36.0	6.0	3.5	4.5	5.7	4.0	297	290	292	295	289	290	190	188	144	152	179	128
21.0	35.7	6.5	4.0	3.5	6.0	3.5												
22.0	35.7	6.5	4.5	4.5	7.5	3.5	297	290	291	294	289	287.5	188	197	145	152	177	127
23.0	36.0	7.0	4.6	4.5	9.2	4.0												
24.0	36.1	7.5	5.2	8.0	7.0	5.0	298	291	292	295	289	289	232	195.5	141	152	178	134
25.0	36.1	6.0	4.0	4.5	8.5	4.0												
26.0	35.9	5.0	4.0	6.5	7.3	4.0	298	291	291.5	294	289	288	234	193	140	156	178	132
27.0	35.9	6.2	4.2	6.0	8.5	4.5												
28.0	36.0	3.0	2.8	5.0	2.8	2.8												
29.0	35.7	6.5	4.0	3.0	6.0	4.0												
30.0	36.1	6.0	3.6	3.5	5.0	3.8	297	291	292	295	289	288	232	191	141	156	178	135
Valve Re-opened																		
31.0	34.9	9.5	7.0	8.0	9.0	5.5												
32.0	35.8	7.0	5.0	6.0	10.0	6.0												
33.0	36.4	6.9	4.7	3.5	5.9	3.9	299	292	293	295	290	289	187	187	138	154	174	132
34.0	36.0	7.3	4.4	5.5	8.8	5.0												
35.0	36.0	6.9	2.0	3.6	2.5	3.5	294	289	287	291	287	284	185	189	140	137	160	126

TABLE 22

Data From Coolant Shutoff Tests on Simulated Shell-Tube Configurations. Test No. 9.13

THERMOCOUPLE LOCATIONS



Conditions:
1. Cooling arrangement across tubes
2. Orifices in tube exits
3. Tube axes horizontal, tubes stacked in horizontal plane
4. Condensing steam flow rate per tube prior to shutoff = 0.022 lb/sec
5. Cooling flow rate per tube prior to shutoff = 0.81 lb/sec
6. Cooling section nearest inlet shut off
7. Small inlet header

Time (seconds)	Mean Pressure Level (psig)	Magnitude of Pressure Oscillations (psi): Inlet Manifold	Exit Manifold	Tube 1 Exit	Tube 2 Exit	Tube 3 Exit	Mean Temperature Levels (°F): T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
0	35.4	0	1.1	2.0	2.0	2.4	312	306	304	289	291	212	187	199	129	125	158	101
1.0	37.0	0	3.3	4.0	3.0	4.0	312	310	311	317	290	213	189	193	130	128	157	99.9
2.0	34.3	0	0	0	0	0	316	312	311	307	306	223	191	199	127	127	152	93
Valve Closed																		
2.1												232						
2.16												252						
2.2												253						
2.28												308						
2.4												311						
3.0	50.5	0	0	0	0	4.8												
4.0	49.0	0	0	0	0	2.4	318	310	313	308	309	310	199	225	143	148	152	98
5.0	47.0	0	1.0	0	0	2.0												
6.0	44.9	0	0	0	0	0	310	306	308	302	302	303	213	230	166	138	171	110
7.0	42.5	0	1.0	0	0	0												
8.0	40.5	0	0	0	0	0	305	306	307	296	295	299	220	232	184	143	173	111
9.0	39.3	0	1.0	0	0	0												
10.0	38.8	0	0	0	0	0	310	306	307	292	292	294	221	232	187	147	175	111
11.0	39.5	0	0	0	0	0												
12.0	39.0	0	1.0	0	0	0	313	308	306	292	291	293	222	237.5	187	153	179	118
13.0	37.4	0	0	0	0	0												
14.0	37.6	0	0	0	0	0	313.5	307	307	291	291	291	222	239	184	151	179	119
15.0	39.0	0	1.0	0	0	0												
16.0	37.5	0	0	0	0	0	313	307	306	291	290	291	223	248	184	154	179	119
17.0	38.9	0	0	0	0	0												
18.0	36.9	C	0	0	0	0	313	307	306	290	289	297	221	259	186	151	182	121
18.2														257				
18.225														276				
18.27														262.5				
18.3														286				
18.35														280				
18.4														289				
18.444														281				
18.6														290				
18.835														288				
18.9														262				
19.0	38.0	0	0	0	0	0												
19.2														264				
19.24														[illegible]				
19.29														271				
19.34														289				
19.394														280				
19.42														289				
20.0	39.0	0	0	0	0	0	313	306	306	293	292	299	224	290	189	154	187	117
20.82														284				
20.84														287				
20.9														286				
21.0	36.2	0	0	0	0	0								265				
22.0	35.1	0	0	0	0	0												
23.0	35.9	0	1.0	0	0	0												
24.0	36.2	0	0	0	0	0	312	307	305	289	297	298	222	244	188	157	194	119

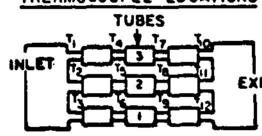
TABLE 22 (Cont'd.)

	Mean Pressure	Magnitude of Pressure Oscillations (psi)					Mean Temperature Levels (°F)											
Time (seconds)	Level (psig)	Inlet Manifold	Exit Manifold	Tube 1 Exit	Tube 2 Exit	Tube 3 Exit	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
25.0	36.0																	
25.5														274				
25.555														260				
25.6														289				
26.0	40.8	0	1.0	0	0	0	314	309	307	294	297	299	227	293	185	154	190	120
27.0	40.9	0	1.0	0	0	0												
28.0	40.7	0	0	0	0	0												
29.0	37.6	0	1.0	0	0	0												
30.0	37.5	0	1.0	0	0	0	313	308	305	290	290	299	221	288	190	157	192	119
Valve Reopened																		
30.6																		134
31.0	25.1	0	1.7	0	0	0	309	303	300	269	269	268	219	267	179	152	178	121
32.0	19.0	0	1.5	0	2.0	2.9												
32.8														252				
32.875														248				
32.886														253				
33.0	21.0	0	.9	0	0	0	306	299	299	259	259	259	210	229	165	151	192	118
33.06														248				
33.3														226				
34.0	25.5	0	1.9	0	1.8	2.0												
35.0	28.4	0	1.4	0	0	1.0	308	302	301	273	273	270	190.5	211	151	134	179	108

TABLE 23

Data From Coolant Shutoff Tests on Simulated Shell-Tube Configurations. Test No. 9.14

THERMOCOUPLE LOCATIONS



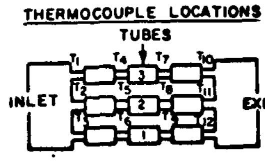
Conditions:
1. Cooling arrangement across tubes
2. Orifices in tube exits
3. Tube axes horizontal, tubes stacked in horizontal plane
4. Condensing steam flow rate per tube prior to shut off = 0.021 lb/sec
5. Cooling flow rate per tube prior to shut off = 0.81 lb/sec
6. Cooling sections shut off - middle
7. Small inlet header

Time (seconds)	Mean Pressure Level (psig)	Magnitude of Pressure Oscillations (psi)					Mean Temperature Levels (°F)											
		Inlet Manifold	Exit Manifold	Tube 1 Exit	Tube 2 Exit	Tube 3 Exit	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
0	36.0	0	1.3	3.0	2.3	2.9	312	307	311	316	293	289	188	199	138	123	156	107
1	43.0	0	3.5	4.8	4.7	4.0												
2	36.5	0	4.1	6.0	5.0	3.9	312	306	303	312	311	314	190	199	147.5	124	158.5	106
Valve Closed																		
3	40.0	0	.5	0	0	0												
4	40.5	0	0	0	0	0	307	308.5	306	298	296	297	193	257	138	130	158	97
5	40.5	0	0	0	0	0												
6	41.0	0	.6	0	0	0												
7	40.5	0	.6	0	0	0	314	309	306	294	298	297.5	219	282	151	132.5	200	97
8	40.6	0	.7	0	0	0												
9	41.1	0	.6	0	0	0												
10	40.6	0	.8	0	0	0	314	308	306	294	296	298	233	292.5	180	139.9	206	101
11	40.2	0	.2	0	0	0												
12	39.6	0	1.0	0	0	0												
13	39.7	0	1.4	0	0	0	312	308	306	294	294	295	235	291	191	150	199	113
14	40.4	0	0	0	0	0												
15	40.6	0	.5	0	0	0												
16	40.4	0	.4	0	0	0												
17	38.8	0	1.0	0	0	0												
18	37.0	0	1.0	0	0	0	311	307	305	290	290	290	260	288	206	159	200	130
19	36.1	0	1.0	0	0	0												
20	39.6	0	.3	0	0	0												
21	39.0	0	.8	0	0	0												
22	33.8	0	1.0	0	0	0												
23	35.0	0	1.3	0	0	0	302	306	303	286	284	283	274.5	284	213	169	201	129
Valve Reopened																		
24	30.4	0	.8	0	0	0	310	305	302	278	279	283	249	277	213	157	188	130
25	27.5	0	1.8	2.0	2.3	3.0												
25.7														262.5				
25.76														240				
25.8														263				
26	26.0	0	1.0	0	2.0	1.8	309	304	301	267	269	268	294	236	204	154	194	134
27	25.5	0	3.7	3.7	4.5	4.0												
28	28.5	0	4.4	3.9	7.0	4.7	310	304	302.5	274	276	272	212	208	174	144	179	136

TABLE 24

Data From Coolant Shutoff Tests on Simulated Shell-Tube Configurations. Test No. 9.15

THERMOCOUPLE LOCATIONS



Conditions:
1. Cooling arrangement across tubes
2. Orifices in tube exits
3. Tube axes horizontal, tubes stacked in horizontal plane
4. Condensing steam flow rate per tube prior to shutoff = 0.021 lb/sec
5. Cooling flow rate per tube prior to shutoff = 0.81 lb/sec
6. Cooling sections nearest exit header shut off
7. Small inlet header

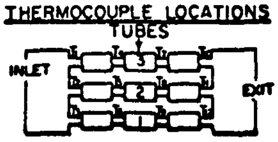
Time (seconds)	Mean Pressure Level (psig)	Magnitude of Pressure Oscillations (psi): Inlet Manifold	Exit Manifold	Tube 1 Exit	Tube 2 Exit	Tube 3 Exit	Mean Temperature Levels (°F): T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
0	35.6	*	5.3	7.3	10.5	9.0	300	292	311	281	290.5	290	195	210	139.5	128	150	106
1	36.6		3.3	6.0	8.6	3.9												
2	36.4		2.8	13.0	6.0	5.5	300	293	295	280.9	293	290	190	203	139	128	161	105.5
Valve Closed																		
3	36.5		0.9	2.6	0.0	1.5												
4	36.5		0.0	2.3	0.0	1.6	300	288	294.5	283	293	291	190	203	138	130	155	99.5
5	36.5		2.7	7.0	6.5	5.0												
6	36.6		3.4	5.6	7.5	3.8	289	290	294	280.5	290.8	289	193	198	143	135	169	104
7	36.4		2.05	3.0	7.0	3.5												
8	36.1		3.8	5.5	7.6	4.5	299.5	290	294	281	291	290	195	203	143.5	138.5	169.5	109
9	36.4		5.3	8.0	12.0	6.5												
10	36.6		1.1	3.0	8.0	2.5	299	290	294	280	295	289.5	189	193.5	147.5	147	174	120
11	36.6		1.0	3.0	0.0	1.9												
12	36.6		1.0	0.0	3.8	1.9	300	290.5	295.5	282	291.5	290	192	193	140.5	149	171	117
13	36.1		3.1	6.0	8.8	9.1												
14	36.4		1.1	0.0	7.0	2.1	299	290	295	281	292	290	190	196	144	151	180	127.5
15	35.9		3.2	4.5	6.5	3.3												
16	36.5		1.1	0.0	2.55	2.0	300	292	295	282	290.8	290	190.5	198	142	153	180	122.5
17	36.6		0.6	0.0	0.0	2.0												
18	36.5		0.5	0.0	0.0	1.5	300	290	296	282	292	290	190	204	140	155	178	123
19	35.8		4.9	5.5	12.0	11.5												
20	36.5		2.1	4.0	10.0	2.3	300	290.5	294	282	292	290	191	200	140	155.5	186	127
21	36.6		5.5	5.5	6.5	5.5												
22	36.4		4.3	5.5	10.0	4.0	300	290.8	295	282	293	290.5	190	194	143	154	180.5	128
23	36.4		4.9	5.0	3.0	5.1												
24	36.5		0.6	0.0	2.1	3.8	300	293	296	283	293	291	190	195.5	141	156	180.5	129.5
25	36.6		1.2	1.9	4.3	2.5												
26	36.4		1.1	1.5	2.55	1.9	300	291	295	283	291	290.5	190	209.5	139	157.5	180	130.5
27	36.4		0.95	0.0	2.7	2.3												
28	36.0		5.0	8.3	13.0	5.8	299.5	290	295	281	292	290	189	197	139	152.5	182	134
29	36.8		4.1	7.0	10.6	5.5												
30	36.5		5.5	8.1	15.0	6.5	300	290.5	293.5	282	292	290.5	190.8	196	143	155	188	133
Valve Reopened																		
31	36.6		6.0	10.0	12.3	6.0												
32	36.3		3.1	5.0	12.2	3.9	298	290.8	294	283	292	289.6	192	200	139.5	158.5	180.5	133
33	36.9		4.85	5.8	11.2	5.5												
34	36.5		5.5	7.3	15.0	6.0	299.5	292	294.5	281.5	290.5	290	193	206	144	159	180.5	137
35	36.3		5.0	5.3	15.0	5.5												
36	36.8		2.2	3.8	7.0	3.0	300	298	296	281.5	291	290	195	193	140.8	160.8	181	140
37	37.0		1.6	0.0	3.0	2.1												
38	37.0		3.9	2.0	8.9	3.8	301	291.5	296.5	283	293	301.5	193	197	142	160	181.5	139
39	37.2		2.9	3.5	9.5	3.0												
40	36.1		5.3	5.5	8.0	9.0	298	290	292	280	290	287	191	200	140	159	183	140.5
41	37.0		5.2	8.0	14.0	6.0												
42	36.9		4.75	7.3	14.0	5.5	301	290	294	282	291.5	290	194	195	143	153	173	138
43	37.0		4.6	3.0	4.8	4.8												136
44	36.9		1.2	4.5	3.0	2.0	300	291	296	284.5	292	293	190.6	195.5	143	142	157.5	124
45	36.8		2.3	2.4	5.0	3.1												117
46	37.2		0.75	0.0	0.0	2.6	301	291.5	296	284.5	293	292	190	198	140	136	156	111
47	36.9		6.05	8.0	19.0	6.0												112
48	36.6		4.3	5.8	11.25	4.5	299	290	291	281	290	290	195	190	144.5	132	160	110.5
49	37.0		4.01	4.95	9.0.	4.0	302	291.5	295	284.5	294	292	190	195	144	134	168	110

*transducer inoperative

TABLE 25

Data From Coolant Shutoff Tests on Simulated Shell-Tube Configurations. Test No. 9.16

THERMOCOUPLE LOCATIONS



Conditions:
1. Cooling arrangement parallel to tubes
2. No orifices
3. Tube axes horizontal, tubes stacked in vertical plane
4. Condensing steam flow rate per tube prior to shutoff = 0.022 lb/sec
5. Cooling flow rate per tube prior to shutoff = 0.81 lb/sec
6. Coolant to middle tube shut off
7. Large inlet header

Time (seconds)	Mean Pressure Level (psig)	Magnitude of Pressure Oscillations (psi) Inlet Manifold	Exit Manifold	Tube 1 Exit	Tube 2 Exit	Tube 3 Exit	Mean Temperature Levels (°F) T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
0	34.5	9	7.0	10.0	13.0	8.5	300	291	292	285	291	239	168	192	128	126	159	109
.04												236						
.10												278						
.20												247						
1.0	34.4	7	5.0	7.0	15.5	6.5	299	290.5	290	281	290.5	248	168	196	130.5	123	160	113
2.0	34.0	11.5	9.0	12.5	13.0	12.0	300	290.5	293	286	291	228	171	192	129	123	152	108
Valve Closed																		
2.65														223				
2.70														291				
3.0	43.3	12.5	7.9	12.5	12.6	12.5	317	305.5	307	299	304	214	167	300	106	124	158	108.5
4.0	47.5	9.0	6.0	17.0	12.7	11.0	321	310	309	301.5	309	213	157	305.5	121	117	170	103.5
4.3																	215	
4.5																	213	
4.75																	309	
5.0	50.5	6.0	3.5	6.5	4.5	7.0	327	316	317.5	309	310	203	157	311	117.5	120	312	104
6.0	50.0	10.0	5.9	13.0	11.0	10.0	325	115	317	307	310	173	167	310.5	106	121	313	98
6.9												246					-	
6.95												290					-	
6.97												267					-	
7.0	48.0	28.0	19.1	21.0	21.0	23.5	321	311	310	301	309		178	305	121	129	308	111
7.2												245					-	
7.25												283					307	
7.35																	240	
7.45																	304	
7.58												267					-	
7.6																	303	
7.7												304					-	
7.8																	170	
8.0	42.5	24.0	3.5	5.0	8.0	7.0	317	305	307	299	300		165	300	134	118	298	100
9.0	43.0	29.0	22.5	25.0	14.0	22.3	315	307	307.5	299	294	307	177	301	130	125	301	100
9.9																	301	
10.0	42.0	54.0	28.8	43.0	24.0	35.0	311	304	301	296	295	302	175	299	155	121	157	110
10.2																	290	
11.0	41.5	33.0	20.5	24.0	19.5	22.6	311	303	305	296	300	304	172	298	154	120	293	106
12.0	41.0	20.0	18.0	21.5	15.0	24.0	310	302	301	292	301	301	172	296	155	123	299	109
13.0	40.5	48.0	28.4	37.3	19.0	32.0	310	301	300.5	292	298	300.5	177	297.5	158	123	300	120
13.4																	295	
13.5																	230.5	
13.6																	290	
14.0	38.5	31.0	21.1	29.0	17.5	27.0	306	300	299.9	291	297.5	299.9	175	293	158	127	295	126
14.1																	258	
14.25																	293	
15.0	40.0	41.0	23.1	36.5	18.0	30.0	310	301	300	292	300	300	171	294	155	121	298	117
15.7																	296	
15.85																	169	
16.0	38.5	38.0	18.9	31.0	18.5	28.0	303	298	298	291	293	298	167	290	150	124	283	117
16.3																	290	
16.45																	165	
16.6																	280	
17.0	38.5	33.0	20.2	27.0	16.5	27.0	307	299	295	291	298	297	158	291	145.5	119	294	110
18.0	40.5	38.0	21.9	31.5	25.0	26.0	308	301	301	294	302	301	163.5	295	142	118	-	110.5
18.45																	296	
18.55																	179	
18.7																	290	
19.0	37.5	32.3	24.2	32.0	23.5	34.0	302	295	297	290	293	293	163	291	153	115	290	110

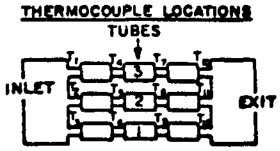
TABLE 25 (Cont'd.)

Time (seconds)	Mean Pressure Level (psig)	Magnitude of Pressure Oscillations (psi): Inlet Manifold	Exit Manifold	Tube 1 Exit	Tube 2 Exit	Tube 3 Exit	Mean Temperature Levels (°F): T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
19.15																	173	
19.3																	279	
20.0	41.0	37.0	17.5	26.0	17.3	27.0	310	303	300.5	293	300	300	160	295	148.5	112	296	106
20.85																	295	
20.92																	200	
21.0	39.0	40.0	25.0	39.0	24.9	27.0	308	300	299	291	300	300	163	295	147.5	120	280	112
21.15																	296	
21.25																	177	
21.5																	294	
22.0	39.0	26.0	19.2	29.0	16.0	27.6	306	300	298	291	299	299	164.5	292	147.5	117	-	110
23.0	40.5	41.0	16.75	35.0	22.0	22.0	309.5	300	300	292	300	300	169	293	147.5	118	-	108
23.2																	295	
23.35																	178	
23.5																	284	
24.0	39.0	48.5	30.9	40.0	28.5	38.0	303	300	300.5	293	297	296	169	294	153	119	322	110.5
Valve Reopened																		
24.15																	173	-
24.4																	291	-
25.0	35.0	7.0	3.6	8.5	6.8	8.0	300	291	293	286	290	291	163	283	148	113	288	109
25.12																	172	-
26.0	22.0	7.1	3.9	7.3	8.0	7.0	275	270.5	268	260	263	263	192	263	170	123	184	114
27.0	18.5	5.5	4.3	7.3	7.3	5.5	269	265	260	253	261	259.5	186	259	167.5	121	163	114
28.0	22.0	0.0	2.4	0.0	0.0	0.0	279	280	270	263	267	265	178	261	169.5	123	175	115
28.2														229			-	-
29.0	24.0	10.0	7.3	12.0	10.5	9.1	284	286	274	265	271	268	180	229	156	125	174	116
30.0	27.0	10.0	6.7	9.0	13.0	8.5	294	288	280	271	278	288	172.5	188	158	125	167.5	119.5
30.6												277					-	-
30.75												248					-	-
31.0	29.0	10.0	6.4	10.6	13.0	10.0	291.9	289.5	284	275	284	247	164.5	188	150	123	179	117
32.0	31.0	10.8	7.3	12.0	16.0	10.5	299.5	290	285	277	285	241	162	183	139	127	174	118
33.0	33.0	9.5	6.45	10.5	13.9	9.5	299	289	290	281	290	238	163	195	131	125	159	111
34.0	34.0	9.5	6.3	11.5	14.0	11.5	300	290	291	284	290.5	229	162	193	122	120	154	117
35.0	36.5	11.0	8.0	11.0	19.0	10.0	302	292	293	287	292	210	162.5	195	116	120	169	105

TABLE 26

Data from Coolant Shutoff Tests on Simulated Shell-Tube Configurations. Test No. 9.17

THERMOCOUPLE LOCATIONS



Conditions:

1. Cooling arrangement parallel to tubes
2. No orifices
3. Tube axes horizontal, tubes stacked in vertical plane
4. Condensing steam flow rate per tube prior to shutoff = 0.022 lb/sec
5. Cooling flow rate per tube prior to shutoff = 0.81 lb/sec
6. Coolant to bottom tube shut off
7. Large inlet header

Time (seconds)	Mean Pressure Level (psig)	Magnitude of Pressure Oscillations (psi) Inlet Manifold	Exit Manifold	Tube 1 Exit	Tube 2 Exit	Tube 3 Exit	Mean Temperature Levels (F°) T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
0.	34.6	6.95	10.5	12.7	12.5	10.3	299.5	290	291	282	290	210.5	169	198	124	122	163	105.5
1.0	35.5	7.0	9.5	11.5	15.0	11.0	299.6	290.5	291	283	290	211	164	200	124	121	153	109.5
2.0	35.5	7.5	12.5	15.0	12.5	11.5	299	290	290	286	290	212-	168	190.5	123	124	160	111
Valve closed																		
2.66												230						
2.8												293						
3.0	38.9	9.0	13.5	14.0	13.0	13.0	307	298	299	291	298	297	167	193	129.5	127	155.5	117
4.0	42.0	6.0	10.0	11.0	13.0	9.5	311	300.5	302	295	303	301	168	198	137	128	160.5	118
5.0	42.55	5.3	7.5	11.5	15.5	8.5	312	302	304	295	303	303	169	192	140	128	156	115
6.0	43.5	6.4	10.0	12.0	15.0	9.5	313	303	306	299	305	304	161	197.5	156	120	147	119
7.0	42.5	7.0	11.0	11.0	12.5	12.0	312	302	304.5	295	303	303	169.5	191	198	128.5	150	127.5
8.0	42.0	6.1	11.0	10.0	15.0	10.0	312	301	303	296	302	303	174	193	259.5	122	160	132
8.53															290			
8.65															272			
9.0	41.5	6.8	9.0	11.5	12.0	9.1	309.5	300	301	293	300.5	300	175	199	271	126	161	145
9.04															279			
9.15															294			
9.3															270			
10.0	39.5	5.3	9.5	9.0	12.5	8.5	307.5	298	299.5	290	299	293.5	176	193	282	125	154	141
11.0	38.5	6.8	10.0	8.5	17.5	9.0	304	297.5	297.5	289	300	290	179.5	202	290	127.5	159	152
12.0	38.9	6.5	9.0	11.0	16.0	10.3	305	298	299	290	298	297.5	181	198	290	129	165	167.5
13.0	38.0	5.5	7.5	7.5	12.7	8.0	304.5	296	297	289	297	295	180.5	200	290	131	166	184
14.0	40.0	5.0	8.0	8.5	12.5	9.0	307	299	297	289	297	297	173	191	290	133.3	161	207.5
15.0	40.0	5.8	8.0	8.0	11.5	8.0	309	299.5	299	291	299.5	299	179	203	291	133	167	209.5
16.0	40.0	6.3	9.5	10.5	12.0	9.5	309	299.5	300	291	300.5	300	181	201	292	130	161	222
17.0	40.0	5.6	7.5	7.0	12.0	7.3	309	299.5	300	291	300	299.5	176	190	292	130	157	230
18.0	41.0	6.1	8.0	7.0	12.5	7.7	307	299	299	291	300	299.5	175	196	290	129.5	166	223
19.0	39.0	5.8	7.8	7.0	18.5	8.0	308	299	299	290.5	299.5	299.	178	196	291	134	158	237.5
20.0	38.0	5.5	8.0	7.3	12.7	8.0	303	295	295	286	295	295	177	193	288	134	167	230
20.7																		205
21.0	36.5	5.9	8.0	7.3	12.5	8.3	301	293	294.5	287	294	293.5	182.5	192.5	287.5	137.5	160	228
22.0	37.0	5.3	7.0	6.5	10.8	7.3	301	294	294	286	295	294	178	192.5	286	128	161.5	257.5
23.0	37.0	5.0	7.7	6.0	9.8	7.6	302	294	295.5	288	295	294	183	197	287.5	130	165.5	257.5
24.0	37.4	5.9	7.8	8.0	12.0	8.0	303	294.5	296	289	296	294.5	178	190	287	134	161.5	260
24.5																		225
24.65																		168
25.0	33.5	5.2	7.0	8.0	14.0	5.3	296	288	288	280	288	286	183	199	280	131	165	211
26.0	36.5	5.1	7.5	7.3	9.0	7.3	301	293.5	293	287.5	294	290	172	194	284	128	152	261
27.0	38.5	5.2	7.3	7.0	12.5	7.5	305	297	296	289.5	296	296	180	189	290	130	166	260
28.0	34.5	7.35	8.0	10.0	15.5	9.0	297.5	292	290.5	281	290	298	180	196	284	134	169.5	263
29.0	35.0	6.3	8.0	7.5	15.0	8.0	300	290	291	283	290	290	183	193	284	135	157.5	242.5
30.0	38.0	4.5	7.0	7.0	12.0	7.5	306	297	289	290	297	297	174	187	290	127	161.5	268

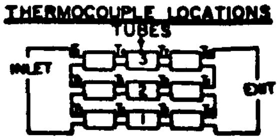
TABLE 26 (Cont'd.)

Time (seconds)	Mean Pressure Level (psig)	Magnitude of Pressure Oscillations (psi)					Mean Temperature Levels (°F)											
		Inlet Manifold	Exit Manifold	Tube 1 Exit	Tube 2 Exit	Tube 3 Exit	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
Valve Reopened																		
31.0	34.5	5.0	7.0	7.1	12.6	7.5	300	291	290	282	292	288	179.5	200	286	137	168	255
31.5																		167.5
32.0	29.0	8.0	11.5	10.8	13.5	11.0	289.5	282	281	273	281.5	278	175	194	273	136	158.5	172
32.28															270			
32.4															230			
33.0	22.0	4.8	7.0	7.8	12.0	7.0	273	277.5	267.5	259.5	267.5	263	183	214	232	131	169.5	153
34.0	21.5	4.8	6.5	8.5	10.0	7.0	288	284	269	259	265	262	179.5	217.5	238	129	161	153
35.0	22.8	6.8	9.8	9.0	13.0	9.6	293	286	271	261	270	266	183	203	230	133	166	161
36.0	26.0	5.2	7.8	8.5	12.5	8.5	296	288	275.5	267.5	275	270	171	190.5	213	137	172	162
36.2												270						
36.28												250						
36.3												270						
36.4												269						
36.7												240						
36.8												267.5						
37	27.6	6.9	10.5	11.0	12.5	10.0	298.5	288	287.5	272	279	274	166	189	190.6	137.5	173	156
38	31.0	6.4	8.0	9.0	12.0	9.0	299	289	290	278	283	281	164	184	153	127	167	136
39	32.8	6.8	9.9	10.5	12.0	10.0	299.5	289	290	280	287.5	280	159	188.95	154	125	154.5	136

TABLE 27

Data From Coolant Shutoff Tests on Simulated Shell-Tube Configurations. Test No. 9.18

THERMOCOUPLE LOCATIONS



Conditions:
1. Cooling arrangement parallel to tubes
2. Orifices in tube exits
3. Tube axes horizontal, tubes stacked in vertical plane
4. Condensing steam flow rate per tube prior to shutoff = 0.022 lb/sec
5. Cooling flow rate per tube prior to shutoff = 0.81 lb/sec
6. Coolant to top tube shut off
7. Large inlet header

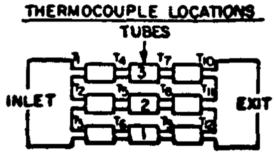
	Mean Pressure Level	Magnitude of Pressure Oscillations (psi)					Mean Temperature Levels (°F)											
Time (seconds)	(psig)	Inlet Manifold	Exit Manifold	Tube 1 Exit	Tube 2 Exit	Tube 3 Exit	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
0	30.6	*	5.0	9.0	13.0	5.0	308	300	300	284	289	287	181	186	146	123	148	120
1	31.0		4.3	6.0	10.5	4.9												122
2	31.5		5.0	5.0	12.5	6.0	309.5	301	301	287.5	290	289.5	180	195	142	120	149	122
Valve Closed																		
3	38.1		2.1	4.0	2.8	7.0												120
4	41.5		4.7	5.0	14.0	6.0	314	305	307.5	301	300	305	184	199.5	137	127.5	153	122
5	41.9		6.0	8.0	15.0	7.3							210					125
5.38													243					
5.425													296					
5.46													280					
5.5													300					
6	43.0		6.6	7.5	13.0	7.5	319	308	304	304.5	310	309.5	303	201	147.5	140	156	127.5
7	43.5		2.3	1.9	5.0	3.0												130
8	43.0		5.95	8.0	12.3	7.0	315	306	309	301	307	307.5	300	200	158	187	150	128
9	43.0		5.9	6.0	16.0	13.0										203		133
10	33.0		5.0	5.1	12.0	6.5	319	307.5	310	305	309	309	302	200	163	273	167.5	132
10.1																300		
11	26.9		2.5	7.0	13.0	6.1												135
12	27.6		4.9	2.3	10.0	6.5	314	304	306	301	305	304	300	200.5	170.5	300	162	142
13	28.0		10.4	6.0	14.0	9.0												143
14	28.0		10.0	5.5	12.0	9.0	309	300	300	296	300	300	295	207.5	174	295	160.5	139
15	28.9		6.75	5.0	14.5	7.0												141
16	29.1		5.8	5.3	17.4	6.9	304	298	294	292	296	295	290	209	183	291	168	150
17	29.2		4.0	5.0	13.0	5.5												148.5
18	29.5		6.6	6.0	11.0	8.8	301	299	297.5	289	293	290.5	285	210	179	287	169	149
19	29.8		7.5	7.0	13.0	9.0												147.5
20	29.6		5.9	5.0	16.5	8.0	300	300	301	290	293	290.5	287.5	210	178	289.5	165	145
21	30.0		6.9	4.5	7.0	8.0												147.5
22	30.5		9.5	4.0	15.0	11.0	302	300	300	288	290	289	285	210.5	175	286	169	148
23	30.5		8.0	8.0	17.5	7.0												145
24	30.0		6.0	5.0	8.5	7.0	300.5	301	301	290	293	292	288	211	171	288	170	143
25	30.0		9.0	5.0	9.5	11.5												147
26	30.5		18.0	5.3	22.0	19.0	300	300.5	301	290	293	290	285	210	170	289.5	165	145
Valve Reopened																		
27	26.0		1.0	9.0	14.0	6.0				277	288		273			276		143
28	6.0		2.4	2.0	7.3	3.0	289.5	290	290	228	238	232	223	193	169.5	173	168	145
29	6.9		2.5	2.5	4.0	2.5												141
30	8.8		3.1	8.0	3.0	3.0	296.5	290	290	240	243	240.5	210	191	169	184	163	138
31	14.9		3.3	4.5	8.5	4.0												134
32	20.0		4.1	4.0	9.0	4.5	303	295	296	268	273	267	164	177.5	181	153	153	129.5
33	26.1		4.3	6.5	9.0	6.5												128
34	28.0		5.9	7.0	16.0	7.0	307	299.5	299	280	284	282	165	190.5	130	130	150	129
35	29.0		5.2	6.0	14.0	7.5	309	299	300	284	288	285	167	181	128	127.5	148	126

*transducer inoperative

TABLE 28

Data From Coolant Shutoff Tests on Simulated Shell-Tube Configurations. Test No. 9.19

THERMOCOUPLE LOCATIONS



Conditions:
1. Cooling arrangement parallel to tubes
2. Orifices in tube exits
3. Tube axes horizontal, tubes stacked in vertical plane
4. Condensing steam flow rate per tube prior to shutoff = 0.022 lb/sec
5. Cooling flow rate per tube prior to shutoff = 0.81 lb/sec
6. Coolant to middle tube shut off
7. Large inlet header

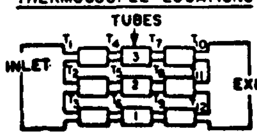
Time (seconds)	Mean Pressure Level (psig)	Magnitude of Pressure Oscillations (psi) Inlet Manifold	Exit Manifold	Tube 1 Exit	Tube 2 Exit	Tube 3 Exit	Mean Temperature Levels (°F) T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
0	35.5	*	5.2	7.3	14.9	8.0	310	302	302	290.5	296	295	176	191	141	120	151	122
1	35.5		4.1	6.0	10.0	6.0												120
Valve Closed																		
2	41.5		4.0	6.5	6.0	7.0	313	304.5	307.5	301	306	304.5	177.5	192	139	120	154	120
3	45.0		0.0	2.6	2.0	2.5								220				
3.4														265				
3.5														301				
4.0	45.0		2.0	2.7	3.5	3.0	320	318	313	306	311	311	175	305	143	122	151	122
5.0	45.0		1.9	2.0	2.8	2.5											167	
5.5																	191	
6.0	45.0		2.1	2.8	3.0	3.5	319.5	309.8	311	306	310	310	192	304	155.5	122	213	125
7.0	43.5		2.5	3.0	3.0	3.1												
8.0	43.0		1.5	3.5	2.8	3.1	316	307	309	303	308	309	191	301	164	128	260	130.5
8.5																	280	
8.55																	300	
9.0	43.0		1.1	3.0	0	2.5												
10	43.5		1.6	4.0	2.0	3.5	318	308	309.5	304	309	308.5	195	302	160	135	305	135
11	41.9		5.7	7.5	0	7.0												
12	41.0		18.0	21.0	1.6	3.0	311	302	306	300	305	304	195	299	166	133	300	138
13	35.0		4.9	12.4	3.0	21.0												
14	37.0		4.9	5.0	3.0	11.0	306	299	298	295	298	298	186	291	169	134	294	138
15	37.0		5.2	7.0	2.5	5.0												
16	35.0		5.2	6.0	1.8	5.5	301	298	304	290.5	296	293.5	187.5	289	169	137.5	291	136
17	36.0		7.5	3.0	1.5	5.1												
18	36.5		18.0	10.0	2.6	8.0	314	300	307	293	299	297.5	182	291	166	149	294	139.5
19	36.5		6.0	8.0	2.7	9.0												
20	35.0		17.6	19.6	2.0	7.3	314	307.5	308	291	298	294	190	290	176	138	293	137
21	34.9		6.0	7.5	4.0	18.0												
22	34.1		4.4	5.0	2.0	8.0	313	306	310	290	294	291	190	289	164.5	139	291	138.5
23	36.0		3.9	5.0	2.5	6.0												
24	34.0		5.0	6.0	4.0	5.0	313	306	310	290	295	291	185	288	170	138	290.5	141
25	36.0		5.2	5.5	2.5	5.8												
26	35.5		8.0	6.0	2.8	7.0	314	307.5	307.3	291	297.5	294	185	289.5	170	139.5	293	139
Valve Reopened																		
27	33.5		16.4	5.5	3.0	6.0												
28	27.7		2.9	3.0	2.5	3.0	311	304	307	281.5	284	283	190	279	168	138.5	281	138
29	12.1		2.0	2.0	2.7	2.48												
30	9.5		1.0	1.5	1.0	2.0	300	292	294	240	243	240	181.5	237.5	172	134	230	138
31	12.0		1.0	1.5	2.3	1.8											199	
32	14.1		3.0	1.8	8.5	2.6	301	292	293	252	259	253.5	160	214	150	127	170	130
33	19.0		4.2	5.0	8.0	3.9								193				
34	23.0		4.1	4.0	8.5	2.5	307.5	300	299.5	270	275	271	150	180	133	120	158	126
35	27.0		4.1	4.9	11.5	4.0												123
36	31.0		4.1	7.0	11.0	5.0	309.5	301	300	282	288	284	161	187.5	126	115	161.5	126

*transducer inoperative

TABLE 29

Data From Coolant Shutoff Tests on Simulated Shell-Tube Configurations. Test No. 9.20

THERMOCOUPLE LOCATIONS



Conditions:

1. Cooling arrangement parallel to tube
2. Orifices in tube exits
3. Tube axes horizontal, tubes stacked in vertical plane
4. Condensing steam flow rate per tube prior to shutoff = 0.022 lb/sec
5. Cooling flow rate per tube prior to shutoff = 0.81 lb/sec
6. Coolant to bottom tube shut off
7. Large inlet header

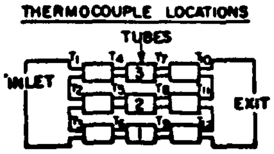
Time (seconds)	Mean Pressure Level (psig)	Magnitude of Pressure Oscillations (psi) Inlet Manifold	Exit Manifold	Tube 1 Exit	Tube 2 Exit	Tube 3 Exit	Mean Temperature Levels (°F) T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
0	29.1	*	4.1	4.6	9.5	6.0	312	304	302	287	291	289	180	190	139	120	156	120
1	29.9		4.9	7.0	12.0	8.0										119.5		
2	29.5		5.45	6.8	14.5	8.0	310.5	302	301.5	287	290	288	179	186	138		152.5	120
Valve Closed																		
3	29.5		4.3	4.0	9.7	7.0										121		
4	30.0		6.4	7.1	14.0	10.0	311	303	303	287	291	289	181	189.5	140		147.5	118.5
5	31.5		5.0	4.9	13.0	6.0										120		
6	37.0		7.0	7.45	17.5	5.0	313	304	307.5	299.5	301	302	179	189	147.5		150	123.5
7	38.1		4.3	4.5	9.0	7.5										121		
8	38.1		6.9	7.0	18.0	10.0	313	303	308	301	303	303	179	183	163		155.5	127.5
9	38.0		4.7	4.0	12.5	7.0									197	128		
10	37.5		4.6	4.6	14.0	7.0	310	302	307.5	299	302	301	183	189.5	237.5		146	138
11	37.3		5.95	5.5	15.1	7.5									273.5	126		
12	36.8		4.0	4.0	9.5	7.0	309.5	300	299	299	301	301	186	183	291		158	158
13	36.3		4.95	4.9	14.0	7.0										127		
14	36.0		3.2	3.0	14.5	5.1	308	299.5	304	297.5	300	300	188	187	291		153	186
15	35.0		5.0	4.5	12.5	7.6										128.5		
15.5														193				
15.88														175				
16	36.5		2.9	2.6	7.0	5.0	309.5	300.5	303	299	301.5	301	187		293		150	213
16.08														173				
16.24														198				
17	36.0		2.4	4.5	6.0	3.5										129.5		
18	36.2		3.0	3.0	7.3	6.0	310.5	299.5	304	290	300	299	189	198	291		149	230
19	37.0		4.1	4.9	13.0	5.0										129		
20	33.5		5.1	5.0	12.5	8.0	305	295	301	292	297	304	190	187.5	289		153	243
21	33.1		3.46	4.0	12.2	9.0										128		
22	33.0		3.35	3.0	10.4	5.0	309	295	301	291	296	296	189	192	289.5		159.5	251
22.5																		262
23	33.0		3.9	3.0	7.3	5.0										129		
24	32.0		4.0	3.5	8.0	5.5	309	301	301	290.5	295	291	189	200	287		150.5	253
25	29.5		5.0	4.5	14.0	7.3										130		
26	33.1		4.75	3.0	15.0	6.5	310	300	301	291	295	303	187	185	287		154	262
27	33.9		4.5	3.4	14.0	6.0										128		
28	34.0		4.1	3.1	12.0	6.0	311	301	300	293	298	303	182	194	290		164	261
29	35.8		4.9	7.6	13	3.1										122		
29.5																		268
30	35.8		5.0	7.0	14	4.1	313	301.5	306	298	300	301	184	193	293		143	277.5
Valve Reopened																		
31	26.0		3.9	6.3	10.5	4.1										126		
31.06																		253
31.24																		235
31.3																		238
31.36																		210
31.54																		193
31.6																		190
31.7																		157.7
32	14.5		4.1	5.5	10.1	4.0	300	291.5	293	260	264.5	258	187.5	187.5	241		150	
33	11.0		3.7	4.0	8.5	3.5										127.5		159
34	13.0		4.0	4.5	11.0	3.8	300	292	293	257.5	260	257	180	175	223		153	
35	18.0		4.2	6.0	9.0	4.5										126		171
36	22.0		4.45	6.5	11.0	5.1	305	297.5	296	272.5	275	271	159	179	194.5		147	
37	25.5		5.1	7.5	10.5	5.1	306	299	299	279	280	289.5	155	177.5	157.5	121.5	147	154

*transducer inoperative

TABLE 30

Data From Coolant Shutoff Tests on Simulated Shell-Tube Configurations. Test No. 3.21

THERMOCOUPLE LOCATIONS



Conditions:
1. Cooling arrangement parallel to tubes
2. Orifices in tube exits
3. Tube axes horizontal, tubes stacked in horizontal plane
4. Condensing steam flow rate per tube prior to shutoff = 0.018 lb/sec
5. Cooling flow rate per tube prior to shutoff = 0.81 lb/sec
6. Coolant to middle tube shut off
7. Large inlet header

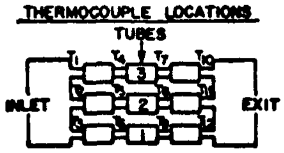
Time (seconds)	Mean Pressure Level (psig)	Magnitude of Pressure Oscillations (psi): Inlet Manifold	Exit Manifold	Tube 1 Exit	Tube 2 Exit	Tube 3 Exit	Mean Temperature Levels (°F): T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
0	*	*	*	*	3.8	4.8	310	303	301.5	289.5	295	293	197	199	144	136	150	104
1					6.0	5.0											148	103
2					14.0	7.5	309.5	300	301	288	293	290	197	197	150.5	137	156	103
Valve Closed																		
3					5.0	5.6											167	101
4					2.7	4.0	311	306	308	299.5	304.5	304	198	250	139.8	138	156	101
4.5														297.5				
5					2.5	2.5											158	101
6					2.1	3.1	311	303	307.5	300	304	304	197	297.5	152	140	187	104
7					3.9	4.0											219.5	105
8					3.0	3.1	311	304	308.5	299.5	304	304	203	297.5	158	139	238	108
9					2.5	3.5											250	107
10					3.0	4.0	309	300.5	307	297	300.5	302	206	296	160	140	259.5	106
11					2.5	2.5											273	110.5
12					2.8	3.0	306	300	304	294.5	300	300	204	292	160.8	146	280	111
13					2.7	3.5											297	114
14					2.1	2.5	309.5	301	306	298	301	302.5	206	296	161.5	146	298	113
15					2.55	6.5											298	114
16					0	11.0	308	300	306	297	300.5	300	200	296	159	144	298	114
17					2.5	6.4											295	119.5
18					2.5	13.0	304	299	303	292	298	297.5	206	290.5	160.5	141	294	121
19					2.2	8.0											298	123
20					2.5	7.5	309.5	307.5	300	298	301	301	190	295	170	142	299	125
21					2.0	8.1											300	129
22					2.3	6.0	307	300	305	295	300	299	198	293	176	144	297.5	132
23					2.23	12.5											298	131
24					3.0	6.0	307	300	304	295	300	299.8	196	293	177	147	297.5	137.5
25					9.0	8.0											299	133
26					3.1	7.5	309.5	303	306	299	304	303	193	293	176	149	300	138
27					6.1	13.1											300	139
28					5.0	7.9	308	302	306	298	302	300.5	191	297.5	184	149	300	139.5
29					6.0	7.9											294	139.5
30					5.8	9.0	303	299	300	293	299	298	196	291	190.5	153.5	296	144
31					3.0	9.5											297	149
32					5.0	12.6	307	300	303	297	300.5	300	190	275	185	152	298	144
33					6.0	19.0											301	143
34					7.3	13.0	310	303	305	299	304.5	303	195	295.5	188	149.5	300.8	141.5
35					6.1	15.0											299.8	143
36					5.8	11.2	309	301	304	298	302	301	196	297	190.6	151.0	300	144
37					5.5	7.0											301	148
38					5.5	23.0	308	299.5	303	297	301	300	199	295	186	154.8	298	147.5
39					5.0	8.3											298.5	145
40					3.1	3.0	301.5	295	300	290.5	294	295	203	289	187.3	150.5	292	145
Valve Reopened																		
41					3.8	3.0										150.0	261	144.5
42					5.0	4.0	290	278	287	252	258	253.5	188	249	181	150.5	250	143
43					2.7	1.9										150.8	174	142
44					2.0	2.5	299.5	290.5	292	260	263	260	173	221	163	149.0	163	130
45					10.1	4.9	301	292	293	268	273	266	166	214	148	139.0	163	122

*transducer inoperative

TABLE 31

Data From Coolant Shutoff Tests on Simulated Shell-Tube Configurations. Test No. 9.22

THERMOCOUPLE LOCATIONS



Conditions:
1. Cooling arrangement parallel to tubes
2. No orifices
3. Tube axes horizontal, tubes stacked in horizontal plane
4. Condensing steam flow rate per tube prior to shutoff = 0.021 lb/sec
5. Cooling flow rate per tube prior to shutoff - 0.81 lb/sec
6. Coolant to middle tube shut off
7. Large inlet header

		Magnitude of Pressure Oscillations (psi)					Mean Temperature Levels (°F)											
Time (seconds)	Mean Pressure Level (psig)	Inlet Manifold	Exit Manifold	Tube 1 Exit	Tube 2 Exit	Tube 3 Exit	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
0	38.5	18.5	7.7	11.0	15.0	14.0	307.5	299	300	289.5	291	290	173	188	136	125	162	100
1.0	39.0	8.0	5.1	7.6	14.5	7.0												
2.0	40.0	8.5	7.5	8.0	15.0	11.25	306.0	299	299	290	291	290	173	204	138	121	155	110
Valve Closed																		
2.4														218				
2.44														285				
3.0	47.5	0	0	0	0	0						223.5						
4.0	49.0	6.5	4.0	10.0	6.5	5.1	318.5	307	309.5	306	309	249	171	300.5	130	120	201	114.5
4.5												200						
4.7																	214	
5.0	49.0	8.0	4.0	18.0	10.0	8.5												
5.2																	260	
5.57																	267.5	
5.6																	296	
5.77																	278	
5.8																	307.5	
6.0	50.0	3.0	3.7	22.0	6.0	7.0	320.0	309.5	313	308	310	227	187.5	305	130	127.5		98
6.6												225						
6.63												289						
6.7												254						
6.9												250						
7.0	47.1	7.3	4.1	15.0	6.0	7.0						305					302	
7.08												268						
7.18												280						
7.2																	284	
7.24												303.5						
7.6																	287	
7.7																	303	
8.0	48.5	3.0	2.0	3.0	0	2.5	318	307	310	305	308.5	308.5	189	301	130	133.5	303	100
9.0	49.5	12.4	8.8	11.0	9.8	10.9												
10.0	44.5	9.0	6.2	6.0	7.3	8.0	310	300.5	303	300	301	302.5	190	295	156	130.5	298	113
11.0	45.5	49.0	23.9	31.0	21.0	27.5												
12.0	43.5	55.0	25.1	35.0	22.8	35.5	310	301.5	300	300	300.5	300.5	166	294	150	120	297	110
13.0	42.0	27.0	12.1	19.0	12.0	8.3												
13.48																	294	
13.6																	177	
13.74																	280	
13.9																	29C	
14.0	39.5	50.0	21.6	29.5	19.0	27.0	300	296	294	290	295	292	165	287	153	119	286	114
14.1																	287	
15.0	41.9	47.0	19.5	25.0	16.0	21.0												
16.0	40.0	38.5	16.5	24.0	22.0	23.0	310	304	297.5	293	296	295	163	289	148	111	291	105
16.82																	295	
16.9																	210	
17.0	42.0	49.0	18.75	31.5	22.0	29.0											285	
18.0	41.5	48.0	25.2	38.0	29.0	37.3	311	306	297.5	293.5	299	297	171	290	153	116	289	109.5
18.1																	204	
18.16																	280	
18.37																	290	
18.5																	176	
18.6																	271	
18.79																	289	
18.9																	180	
19.0	39.5	43.0	17.2	26.5	20.0	22.5											178	

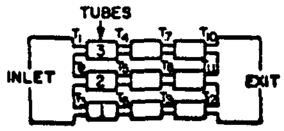
TABLE 31 (Cont'd.)

Time (seconds)	Mean Pressure Level (psig)	Magnitude of Pressure Oscillations (psi) Inlet Manifold	Exit Manifold	Tube 1 Exit	Tube 2 Exit	Tube 3 Exit	Mean Temperature Levels (°F) T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
19.2																	289	
19.3																	183	
19.4																	280	
20.0	41.0	42.1	26.0	30.0	17.76	27.0	311	305	303	291	297	295	154	289.5	151	106		103
20.5																	289	
20.65																	172	
20.8																	282	
20.96																	288	
21.0	39.0	50.0	22.0	33.0	22.3	31.0											225	
21.3																	290	
21.4																	209	
21.45																	280	
21.94																	290	
22.0	40.0	67.6	24.6	40.0	28.0	36.5	312	303	303	291	296	293	160	288	141	104		100
22.05																	176	
22.18																	280	
22.4																	290	
22.5																	213	
22.6																	288	
22.8																	293	
22.87																	230	
22.94																	290	
23.0	41.5	52.3	19.4	30.0	20.0	27.5												
Valve Reopened																		
23.45																	292.5	
23.49																	287.5	
23.53																	290	
23.74																	290	
23.85																	179	
24.0	40.0	22.0	19.1	20.5	17.5	12.6	302	303	310	293	294	290	157	289	143	103		99
24.04																	284	
24.07																127		
24.17																124		
24.4																102		
25.0	36.5	7.0	4.4	6.5	7.7	6.5											285	
25.3																	190	
26.0	20.0	9.5	7.0	8.5	9.0	8.0	290	286	299	243.5	251	245	180	247	174	105.5	203	100
27.0	19.0	8.0	5.3	7.0	8.0	7.0												
28.0	22.0	4.9	2.9	4.0	4.9	4.0	290	285	300	253	259.5	255	179	255	169	117	168	113
29.0	27.0	7.6	5.0	6.5	6.0	6.0												
30.0	32.5	12.5	7.3	8.5	12.4	10.0	295	295	305	273	276	277.5	160	207	143	125	143	108
31.0	35.0	12.6	7.55	8.0	13.0	10.0												
32.0	37.5	13.0	7.6	11.0	14.5	10.0	300	300	309	289	290	289	160	193.5	127.5	132	188	106
33.0	38.1	12.0	7.7	11.5	17.5	10.0												
34.0	39.5	12.0	7.1	12.5	14.9	9.9	301	298	309	249	292.5	290	170	196	126	120	163	113

TABLE 32

Data From Coolant Shutoff Tests on Simulated Shell-Tube Configurations. Test No. 9.23

THERMOCOUPLE LOCATIONS



Conditions:

1. Cooling arrangement parallel to tubes
2. Orifices in tube exits.
3. Tube axes vertical
4. Condensing steam flow rate per tube prior to shutoff = 0.018 lb/sec
5. Cooling flow rate per tube prior to shutoff = 0.81 lb/sec
6. Coolant to middle tube shut off
7. Large inlet header

Time (seconds)	Mean Pressure Level (psig)	Magnitude of Pressure Oscillations (psi) Inlet Manifold	Exit Manifold	Tube 1 Exit	Tube 2 Exit	Tube 3 Exit	Mean Temperature Levels (°F) T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
0	25.0	*	3.8	*	7.5	7.0	346	337	339	285	285	287.5	191	171	167	150	139	122
1	23.5		1.6		3.0	2.5												
Valve Closed																		
2	26.5		3.1		4.5	5.5	346	337.5	339.5	290	290.5	290	193	170	161	155	143	130
3	30.5		1.6		2.5	2.5												
4	32.2		2.7		4.0	4.5	347	337.5	339.5	299	299.5	300	205	184	179.5	163	148	126
5	29.8		3.3		5.0	5.0												
6	31.0		2.0		1.5	3.0	346	338	339.5	298	299	299	211	217.5	189.5	167	148	130
7	29.0		3.0		5.0	4.5												
8	30.2		2.7		3.1	3.9	347.5	338	339.5	294	299	297	210	254	189	163	144	133.5
9	27.4		.9		0	1.5												
10	28.0		.75		1.0	1.5	348	337.5	339	292	294	292	219.5	261	189	177	148	138
11	28.3		.5		0.9	1.9												
11.55														263				
11.59														282				
11.67														264				
11.9														264				
11.91														281				
11.96														268.5				
12.0	28.7		.8		.9	1.5	348	337	339	294	297	293.5	218	283	180.5	177.5	154	138
12.08														287.3				
12.23														270				
12.28														289				
12.36														287.5				
12.38														280				
12.4														287.5				
13	28.1		1.0		1.1	1.5												
14	27.4		1.0		0.9	1.4	347.5	336	338	291	293	290.5	218	287.5	176	177.5	167	139
15	26.7		.75		0	0												
16	26.0		.9		0	0	348	336	338	289.5	290	289	215	287	171	180	172	135
17	26.7		.4		0	0												
17.9					16.0													
18	27.0		.8		0	1.25	348	337	339.5	290	291	290	210	289	175	177.5	179	136
19	25.0		1.6		3	3.5												
20	26.3		.8		2	1.5	348	335	339	289	292.5	289	213	289	173.5	173	180.5	137.5
21	27.0		0		0	0												
22	26.5		.6		0	1.0	348.5	336	339.5	290	291.5	290	209	287	180	181	193	140
23	26.0		.9		1.0	1.9												
23.7					25.0													
24	26.3		.6		3.9	1.25	348.5	337	339.5	290	291	289	213	285.5	185	180	188	138
25	22.5		.4		4.5	0												
26	25.7		..1		0	1.0	348.5	337	340	289	290	289	208	285	188.5	177	187	136
27	27.0		.6		0	2.0												
28	26.8		0		0	0	348.5	337.5	340	290.5	293.5	290	216	287.5	186	176	201.5	137
29	26.2		1.1		2.5	2.0												
30	25.9		.25		1.5	1.5	348.5	337.5	339.5	289.5	292	289.5	208	285	190	170	194	137
31	25.0		.1		0.	0.												
32	25.9		.95		2.0	2.0	349	337.5	340	290	291	289.5	212	285	136	179	201.5	136
33	26.0		.4		0	1.0												
34	26.1		.9		0	1.25	349	336	339.5	289	291	289.5	210	285	186	170	201	141.5
35	24.9		.3		0	0												
36	25.4		.95		0	0	349	337	340	289	290	288	210	284	187.5	175	198	141
37	23.7		.5		0	1.0												
38	24.5		.9		1.5	1.1	346	337.5	339.5	285	289.5	286	207	282	187.5	175	193	140

*transducer inoperative

TABLE 32 (Cont'd.)

Time (seconds)	Mean Pressure Level (psig)	Magnitude of Pressure Oscillations (psi)					Mean Temperature Levels (°F)											
		Inlet Manifold	Exit Manifold	Tube 1 Exit	Tube 2 Exit	Tube 3 Exit	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
Valve Reopened																		
38.7					12.4													
39	19.9		.9		1.5	1.1											179	
39.16														281.5				
39.18														260				
40	15.5		.6		0.8	1.25	347	336	339	270	270.9	269	190.5	245	173	171	150	137.5
41	14.0		1.9		10.9	6.0												
42	15.6		2.2		7.0	7.5	346	337	339	271	272	271	181	213	160	159.5	150	137.5
43	17.5		1.2		4.5	4.0												
44	17.5		2.8		7.3	7.0	345	335	339	272	274	271	185	179	157.5	156	161	128
45	18.9		2.3		4.5	7.3												
46	19.0		1.6		3.0	5.5	347	337	339	276	277.5	275	182	179	168	153	152.5	129.5
47	19.5		2.0		4.0	4.0												
48	20.1		2.1		4.0	4.0	346	337	349.5	280	280	280	180	176	163	150	143	118

TABLE 33

Test Data for Simulated Condensing Radiator Configuration

Test Number	Condensing Steam Flow Per Tube (lbs/sec)	Cooling Flow Per Tube (lbs/sec)	Static Pressure at Inlet (psia)	Steam Temperature in Inlet Manifold (°F)	Temperature at Inlet of Bottom Tube (°F)	Temperature at Inlet of Middle Tube (°F)	Temperature at Inlet of Top Tube (°F)	Coolant Temperature (°F)
10.01	.0042	.78	50.3	320	309.5	294	291	52
10.02	.0031	.78	50.3	318	309	288	287	52
10.03	.0022	.78	50.5	322	289	284	282	52
10.04	.0022	.78	50.3	320	287	283	282.5	52
10.05	.0019	.78	50.3	322	167	284	281	52
10.06	.0019	.78	49.8	322	207	292.5	282	52
10.07	.0016	.78	49.8	310	80	289	281	52
10.08	.0014	.78	50.3	330	61	290	281	52
10.09	.0011	.78	50.7	324	77.5	286	279	52
10.10	.00078	.78	50.3	314	69	288	282	52

APPENDIX 2
Figures

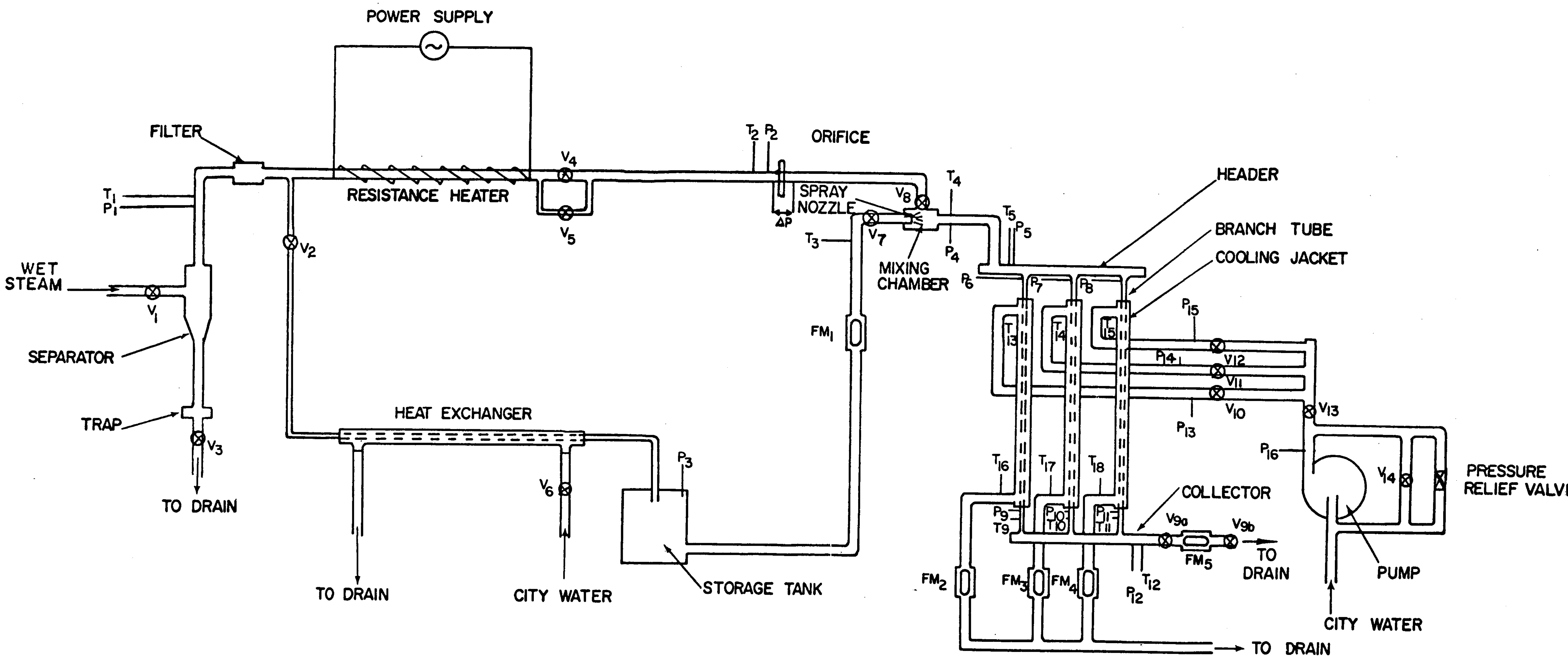


Figure 1 Schematic Diagram of Condensing Stability Rig

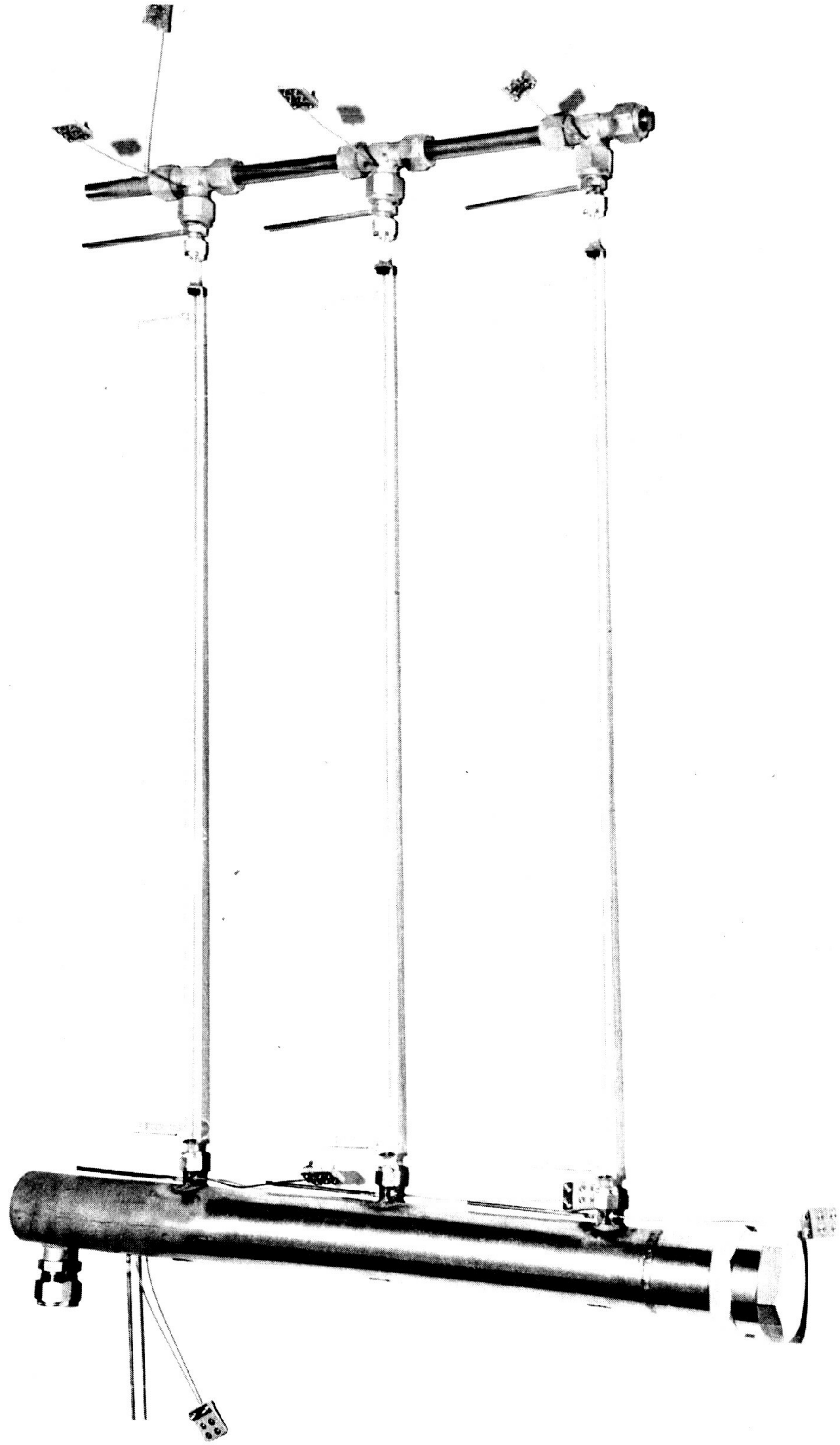


Figure 2 Glass Tube Configuration

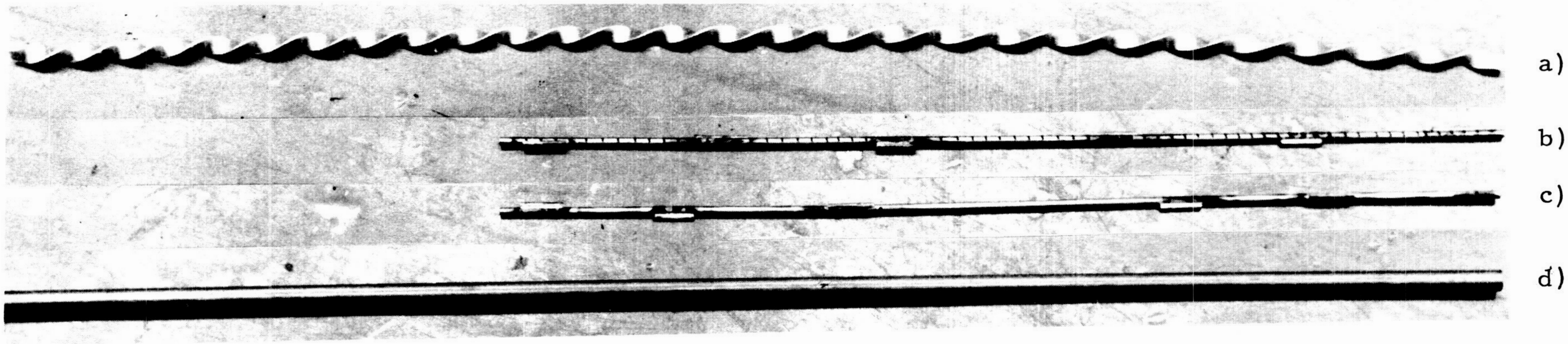


Figure 3 Insert Test Sections
a) Swirler Insert
b) Slotted Tubular Insert
c) Nonslotted Tubular Insert
d) 0.43-Inch Inside Diameter Condensing Tube

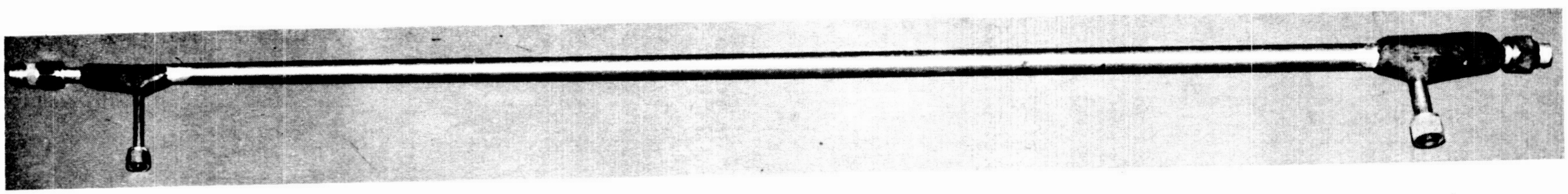


Figure 4 Tapered Tube Configuration

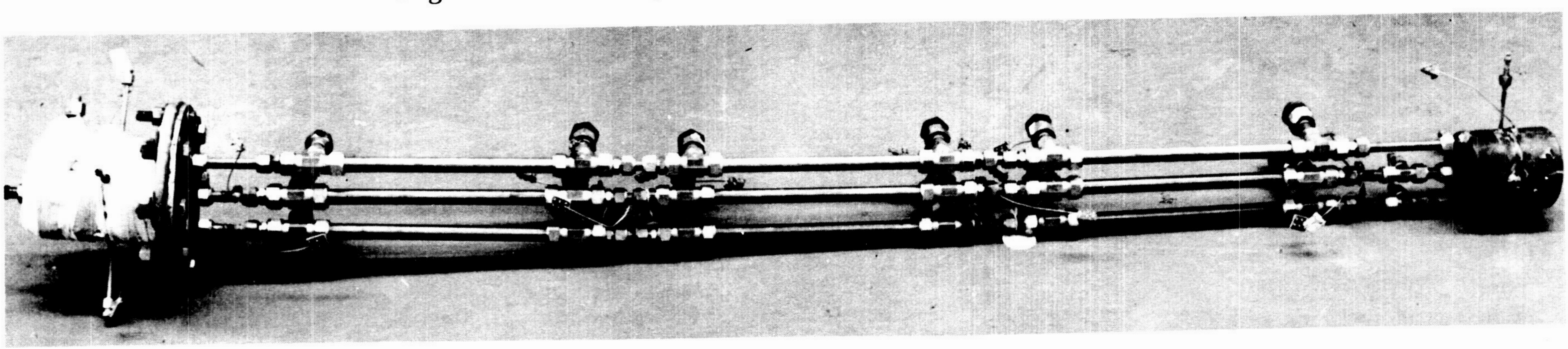


Figure 5 Simulated Shell-Tube Configuration

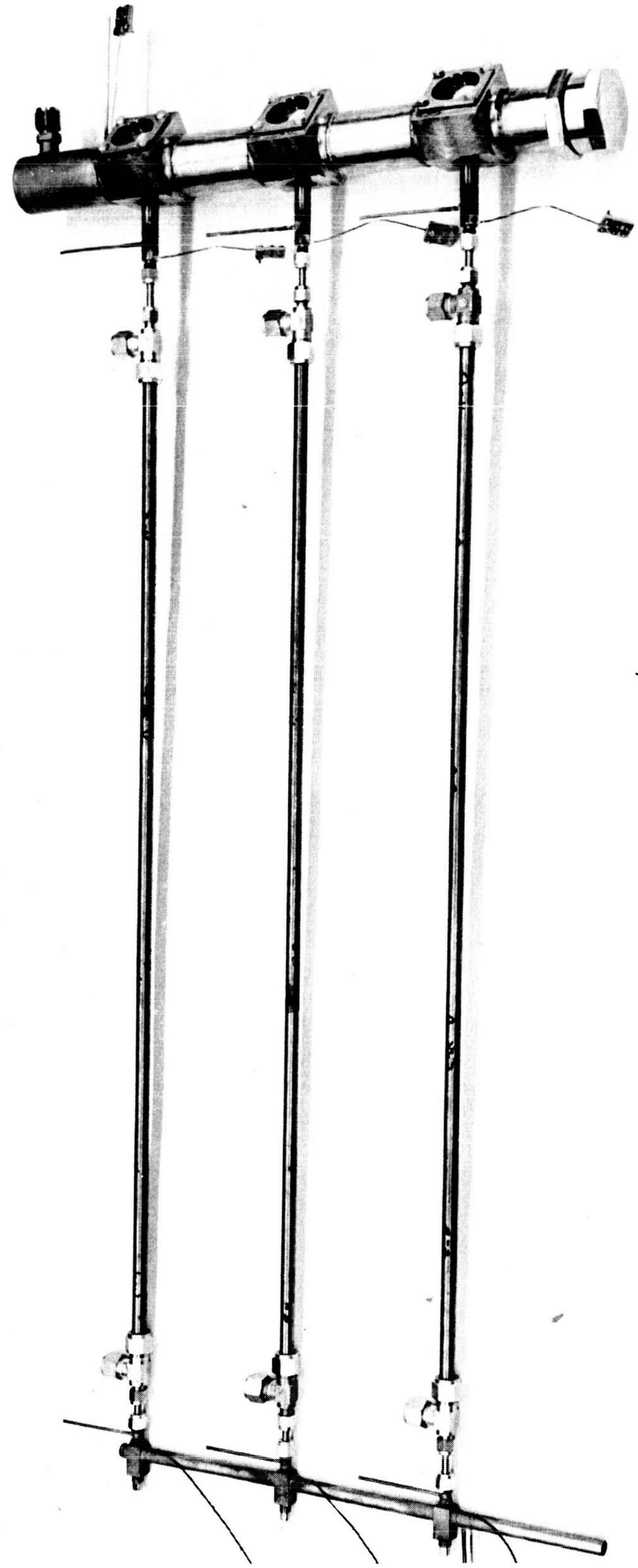
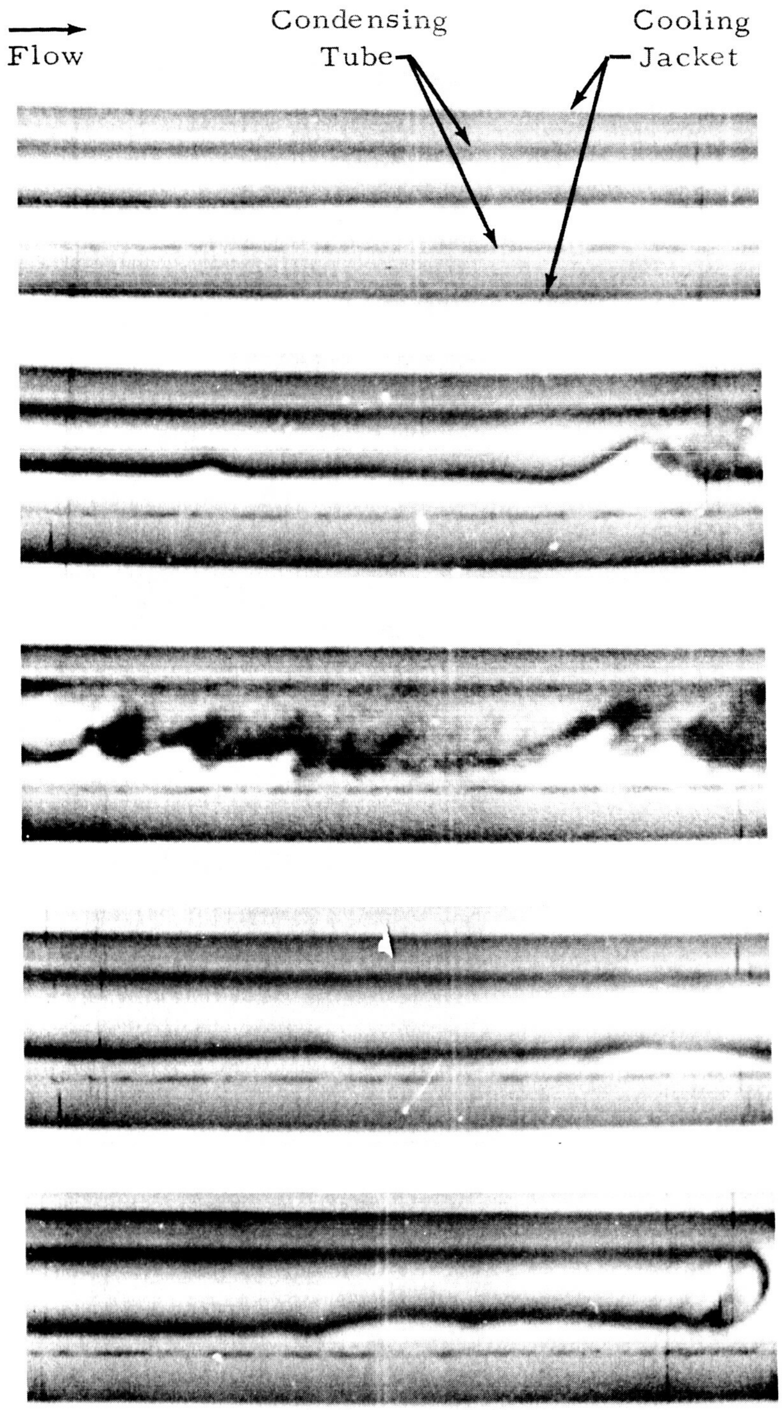


Figure 6 Simulated Condensing-Radiator Configuration



a) Time = 0
Beginning of sequence showing calm condensate film on bottom of condensing tube

b) Time = 0.032 second
Waves formed in condensate film

c) Time = 0.0364 second
Condensate completely turbulent

d) Time = 0.096 second
Condensate film becoming calm

e) Time = 0.128 second
Final liquid-vapor interface at right edge. Condensate film indicates back flow of liquid

Figure 7 Sequence from Movie Showing Sporadic Flow Typical of Slugging Flow (Side View - 2X Magnification)

<u>Conditions</u>:
1. Condensing Flow Rate per Tube = 0.00078 lb/sec
2. Static Pressure at Inlet = 19.2 psia
3. Inlet Velocity = 86 ft/sec
4. Inlet Quality = 1.0
5. Two Glass Tubes in Horizontal Plane
6. Camera Speed = 5000 Frames per Second

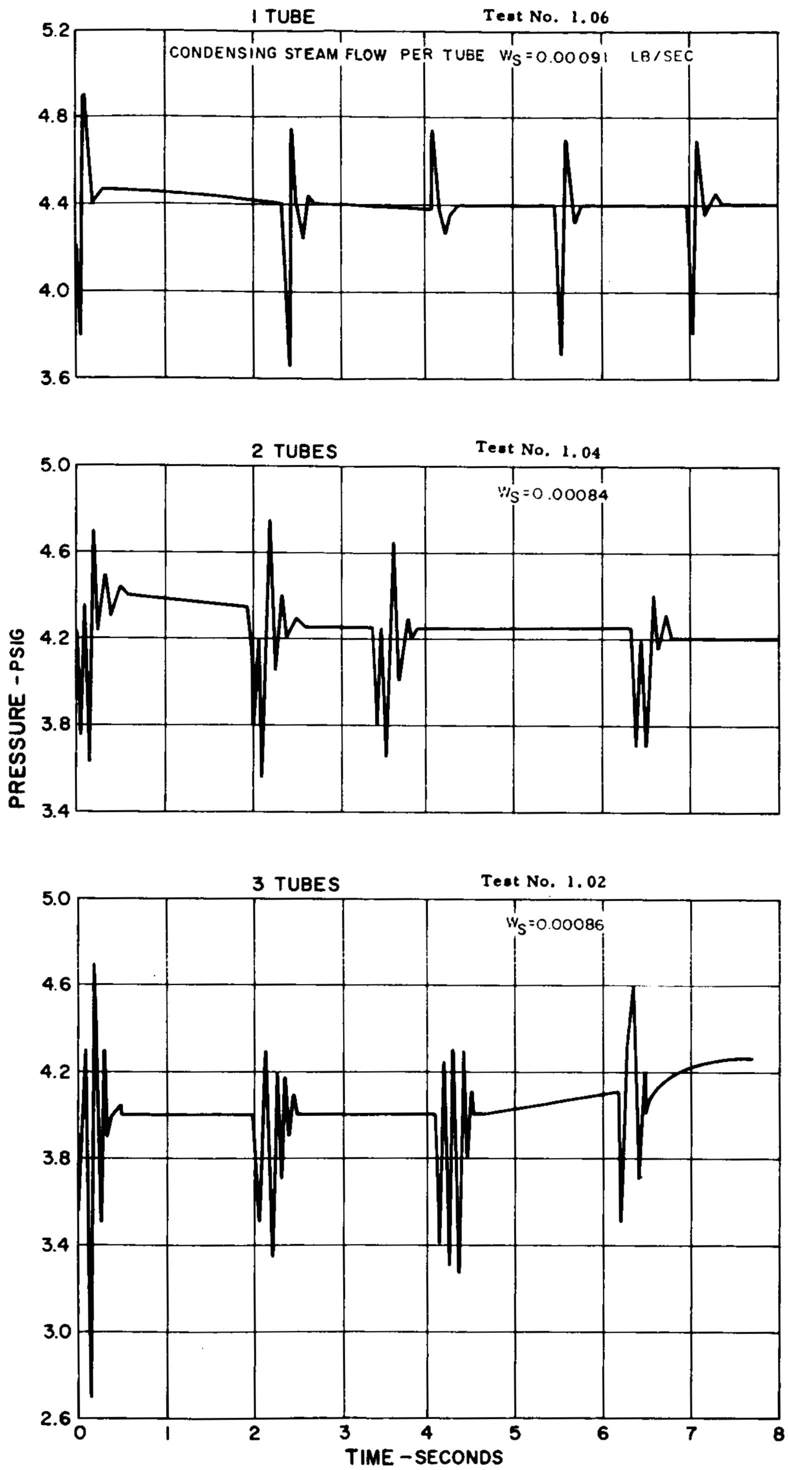


Figure 8 Typical Curves of Pressure at Tube Exit vs Time, Showing Effect of Number of Tubes for Glass Tube Configurations.

Conditions:
1. 2° Uphill Orientation
2. Cooling Flow per Tube $W_C \approx 0.28$ lb/sec
3. Static Pressure at Tube Inlet $\approx$ 20 psia

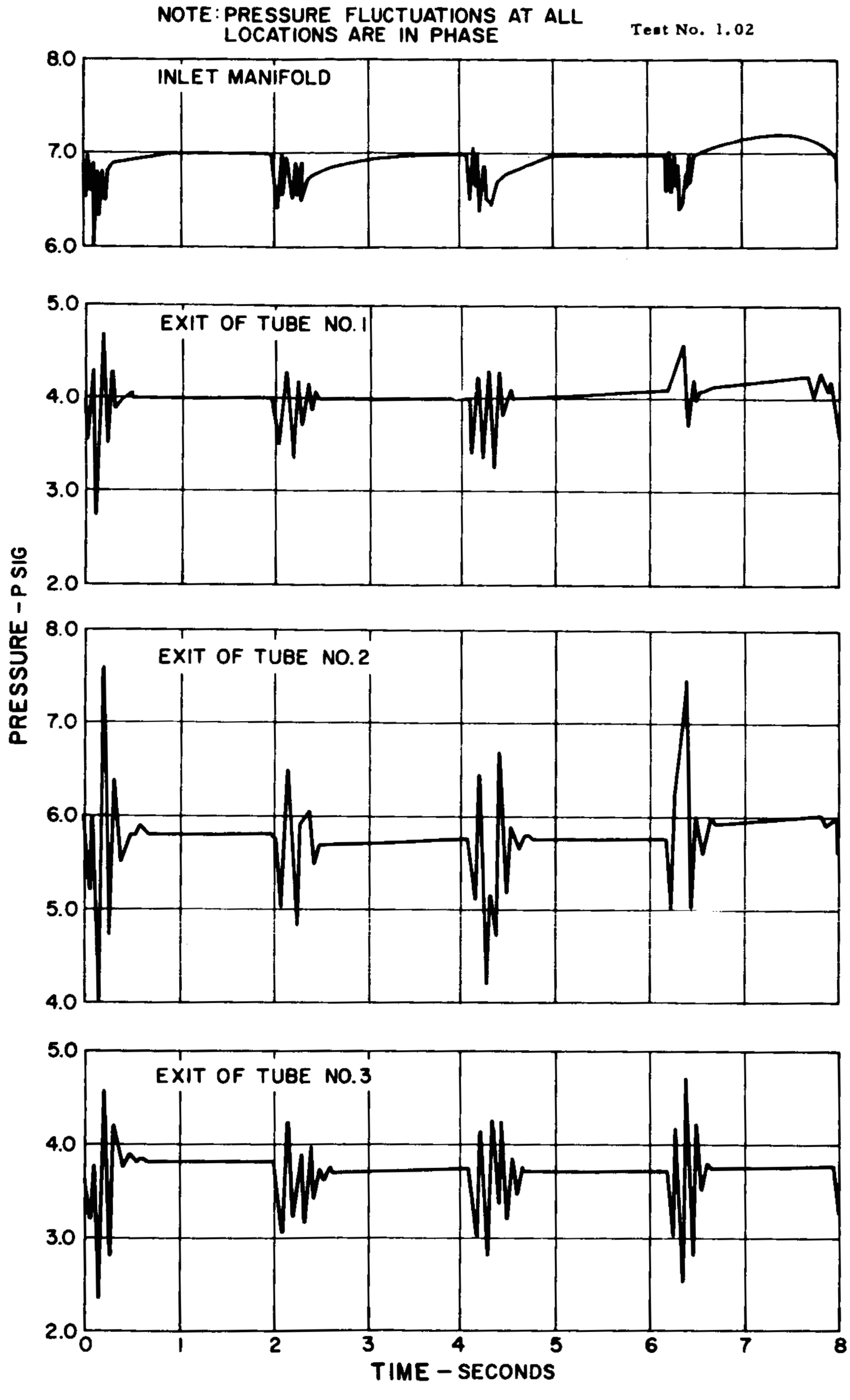


Figure 9 Typical Curves of Pressure vs Time for Three-Glass-Tube Configurations at Various Locations.

Conditions:

1. **2° Uphill Orientation**
2. Condensing Steam Flow per Tube W_s = 0.00086 lb/sec
3. Cooling Flow per Tube W_c = 0.28 lb/sec
4. Static Pressure at Tube Inlet ≈ 20 psia

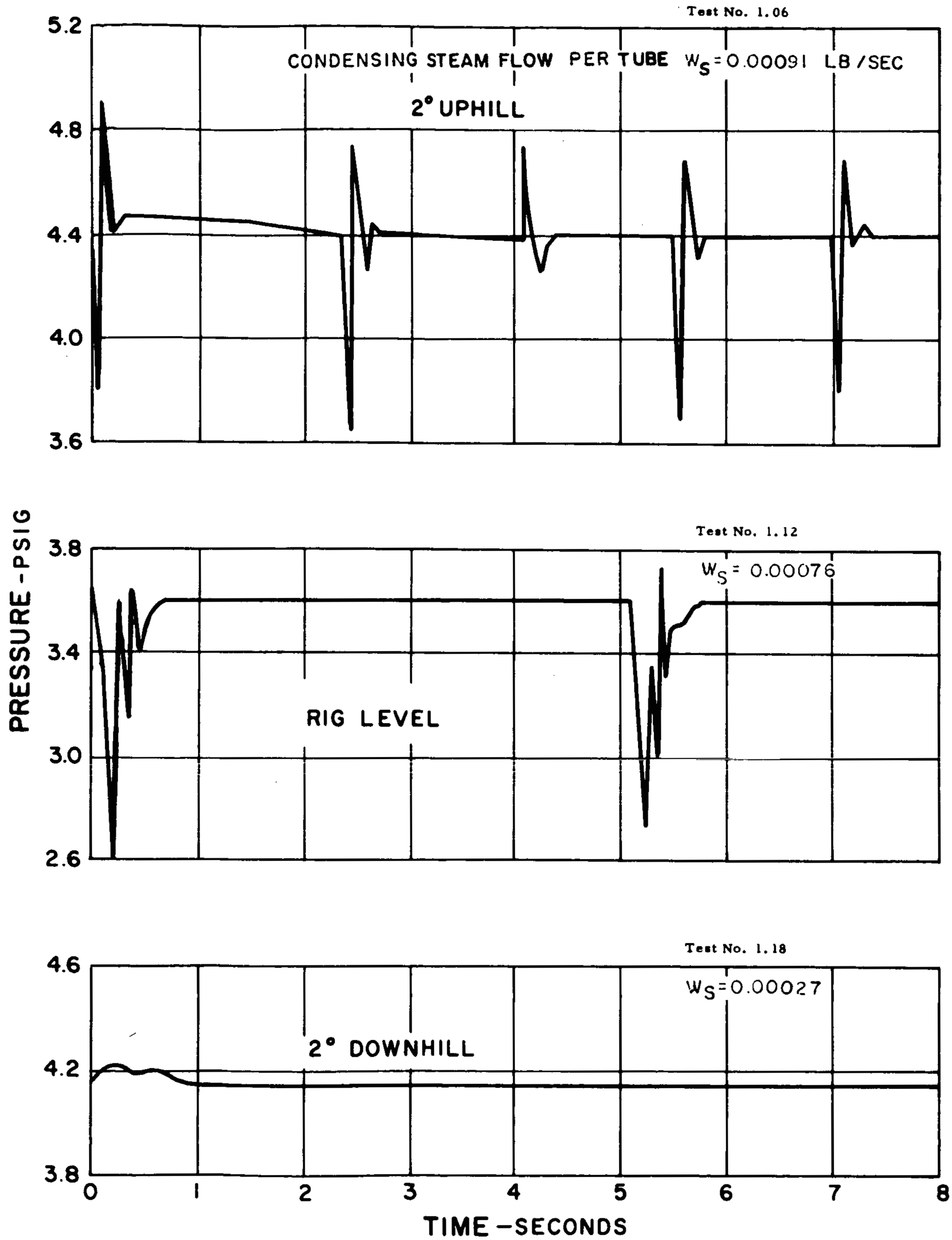


Figure 10 Typical Curves of Pressure at Tube Exit vs Time, Showing Effect of Angle of Tube Inclination.
Single Glass Tube Configuration
Conditions:
1. Cooling Flow $W_C \approx 0.27$ lb/sec
2. Static Pressure at Tube Inlet ≈ 20 psia

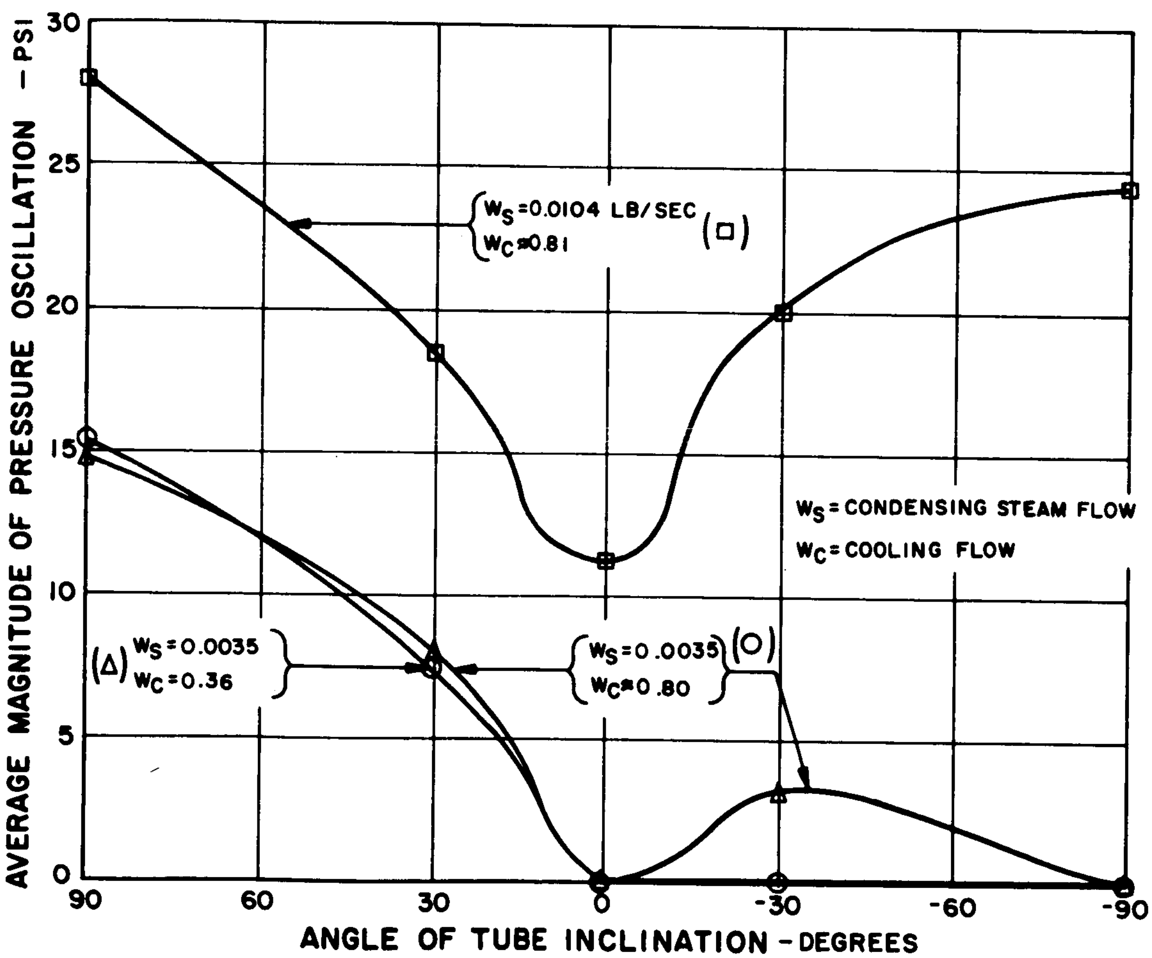


Figure 11 Average Magnitude of Pressure Oscillation at Exit of Condensing Tube vs Angle of Tube Inclination.
Configuration: Single Tube, Constant 0. 18-Inch Inside Diameter
Static Pressure at Tube Inlet ≈ 50 psia

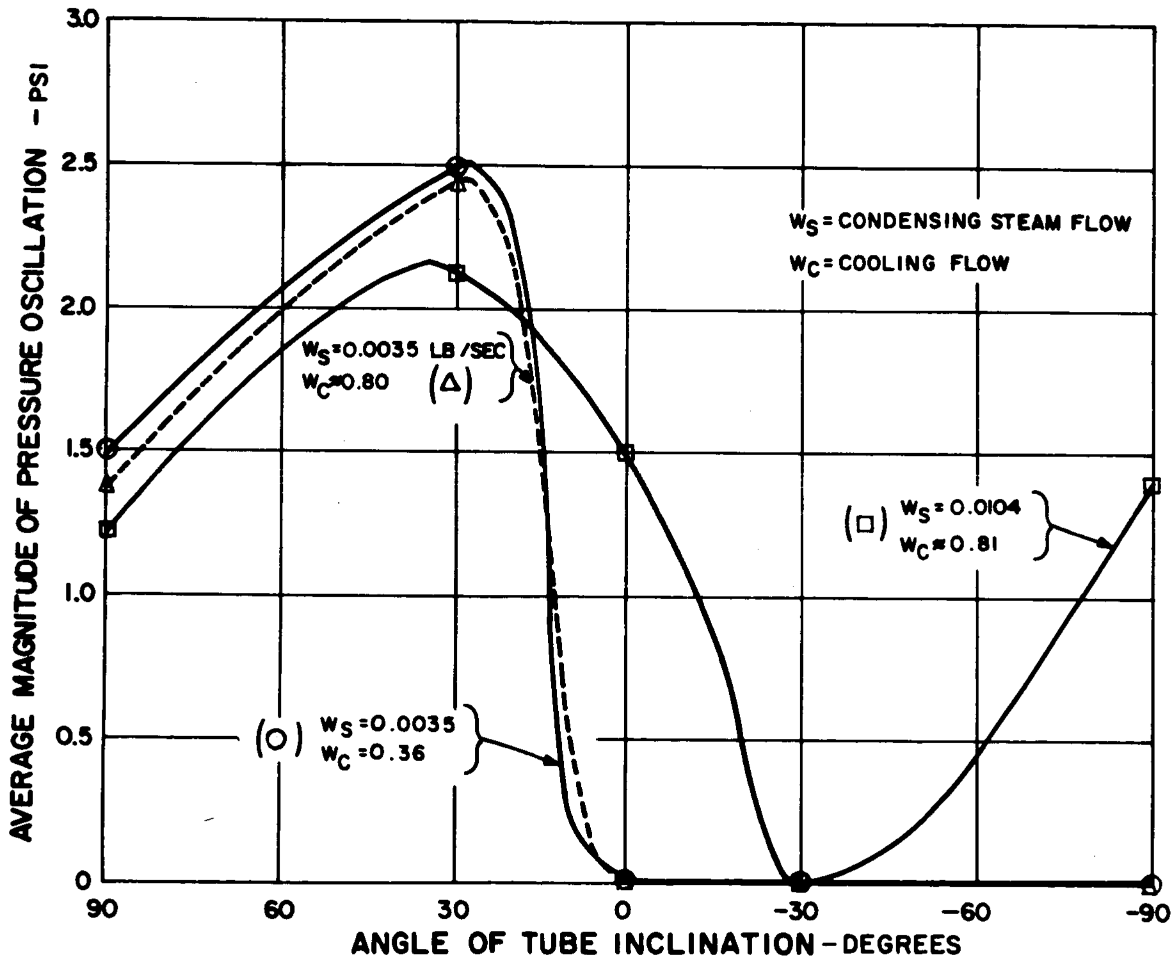


Figure 12 Average Magnitude of Pressure Oscillation at Inlet of Condensing Tube vs Angle of Tube Inclination.
Configuration: Single Tube, Constant 0.18-Inch Inside Diameter
Static Pressure at Tube Inlet ≈ 50 psia

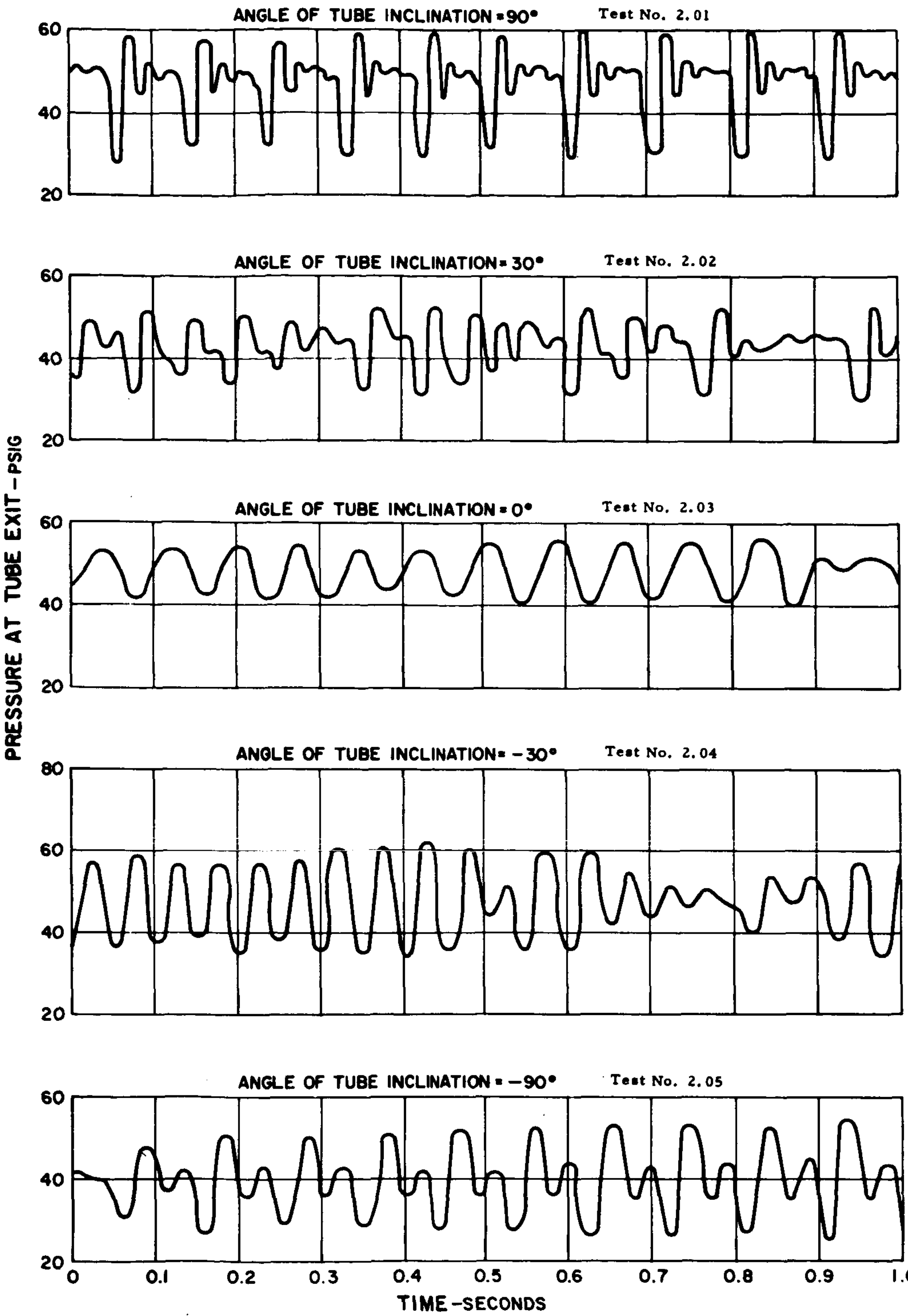


Figure 13 Typical Curves of Tube Exit Pressure vs Time for Various Angles of Tube Inclination.

Configuration: Single Tube, Constant 0.18-Inch Inside Diameter

Conditions:
1. Condensing Steam Flow W_s = 0.0104 lb/sec
2. Cooling Flow $W_c \approx$ 0.81 lb/sec
3. Static Pressure at Tube Inlet $\approx$ 50 psia

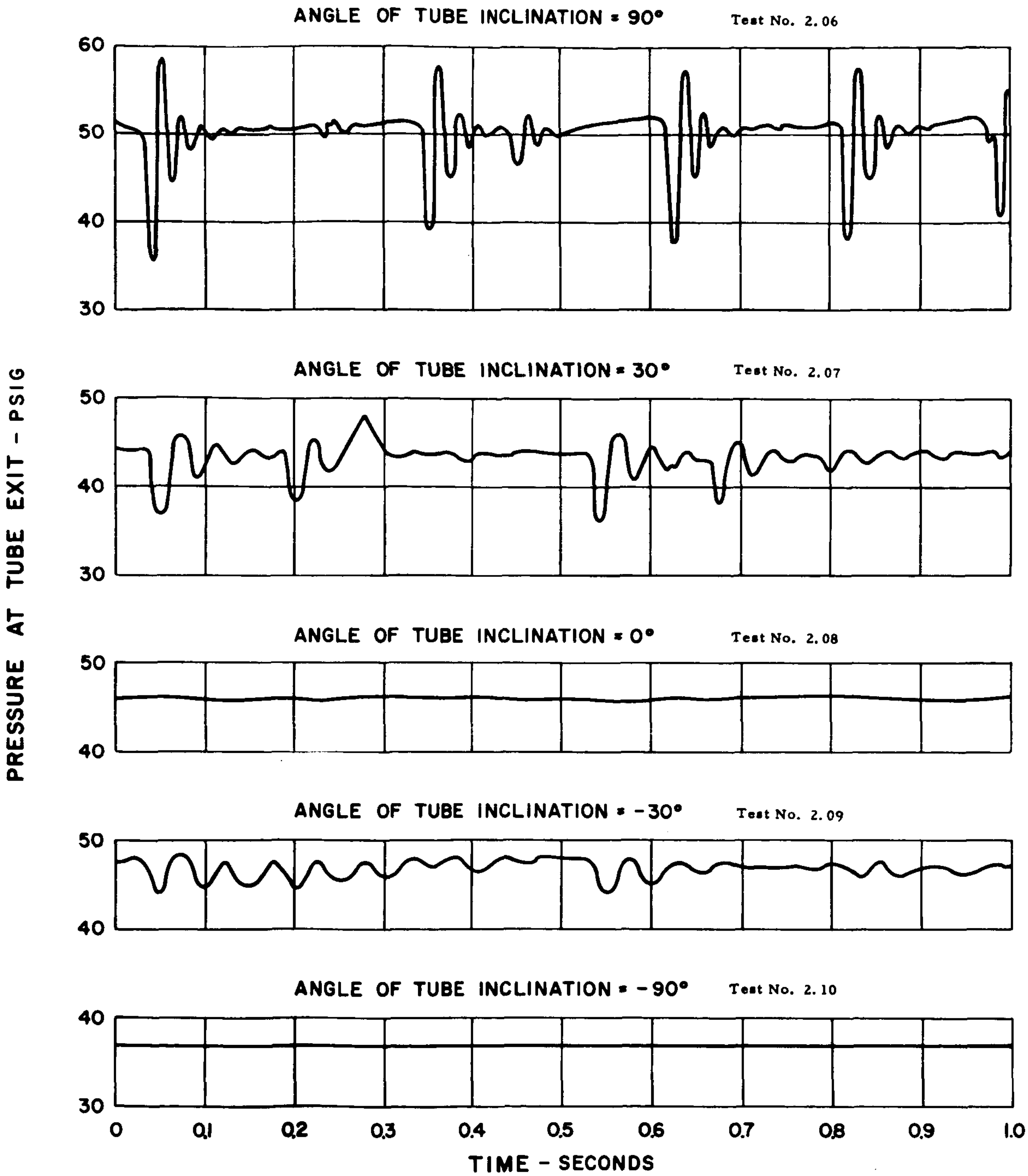


Figure 14 Typical Curves of Tube Exit Pressure vs Time for Various Angles of Tube Inclination.

Configuration: Single Tube, Constant 0.18-Inch Inside Diameter

Conditions:
1. Condensing Steam Flow $W_s = 0.0035$ lb/sec
2. Cooling Flow $W_c \approx 0.80$ lb/sec
3. Static Pressure at Tube Inlet $\approx$ 50 psia

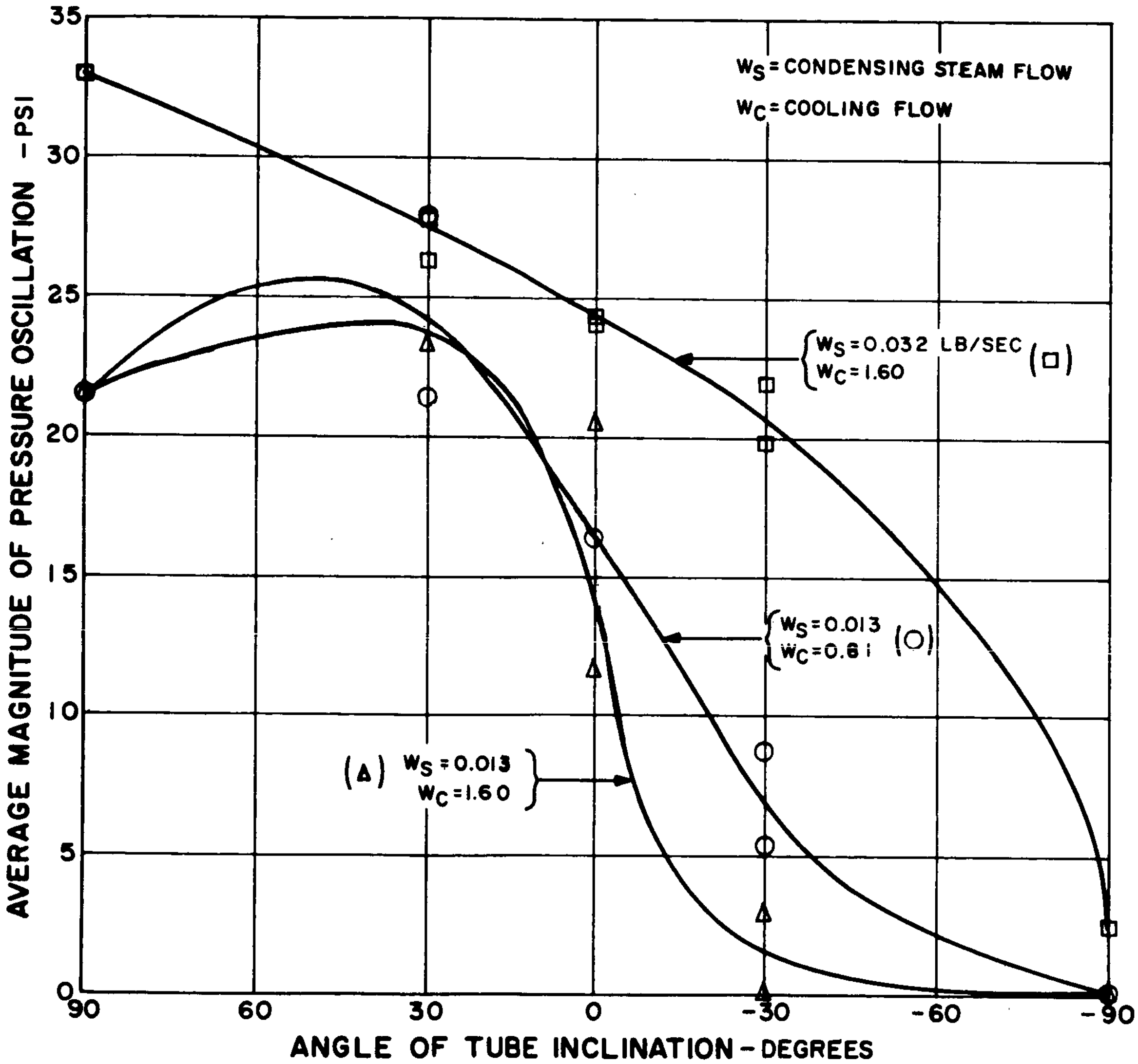


Figure 15 Average Magnitude of Pressure Oscillation at Exit of Condensing Tube vs Angle of Tube Inclination.
Configuration: Single Tube, Constant 0.305-Inch Inside Diameter
Static Pressure at Tube Inlet ≈ 50 psia

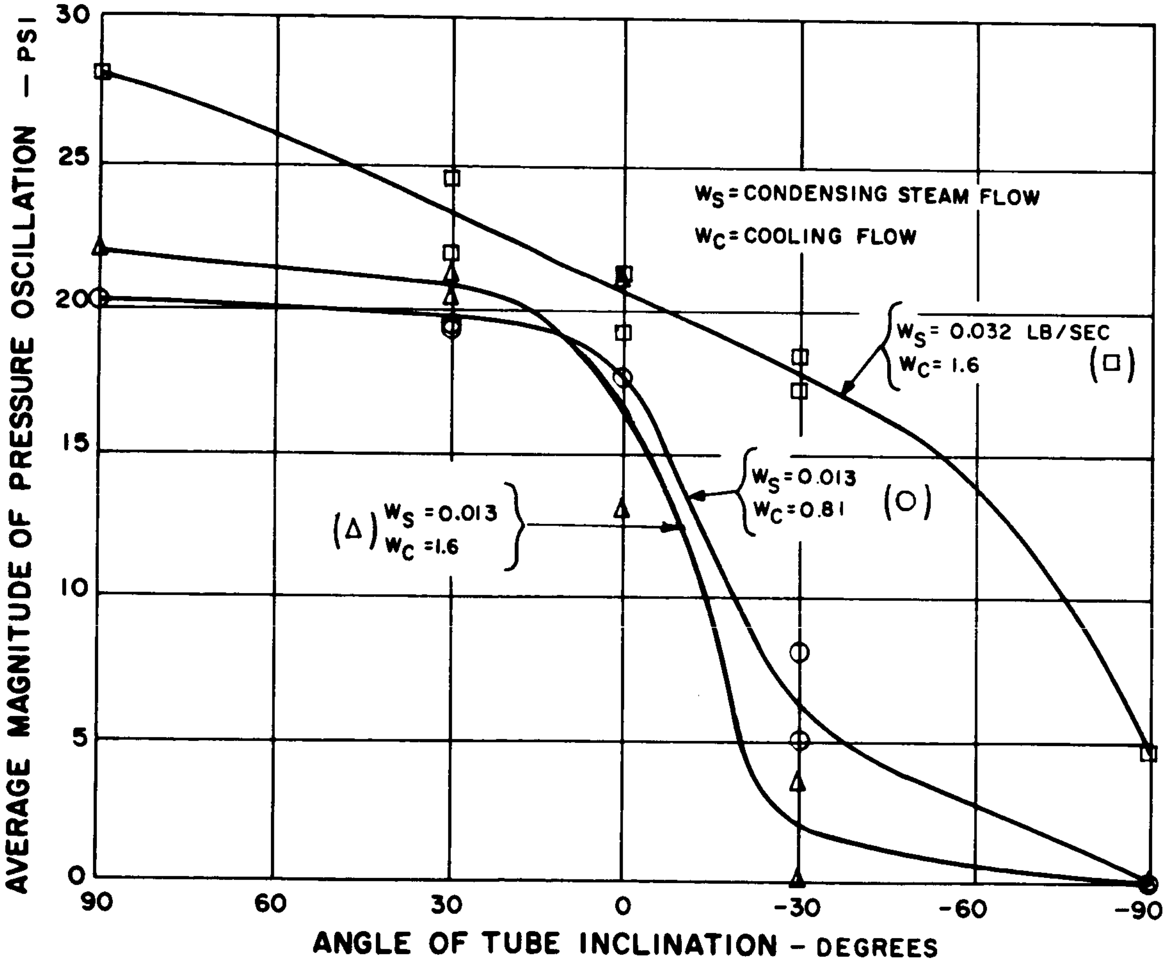


Figure 16 Average Magnitude of Pressure Oscillation at Inlet of Condensing Tube vs Angle of Tube Inclination.
Configuration: Single Tube, Constant 0. 305-Inch Inside Diameter
Static Pressure at Tube Inlet ≈ 50 psia

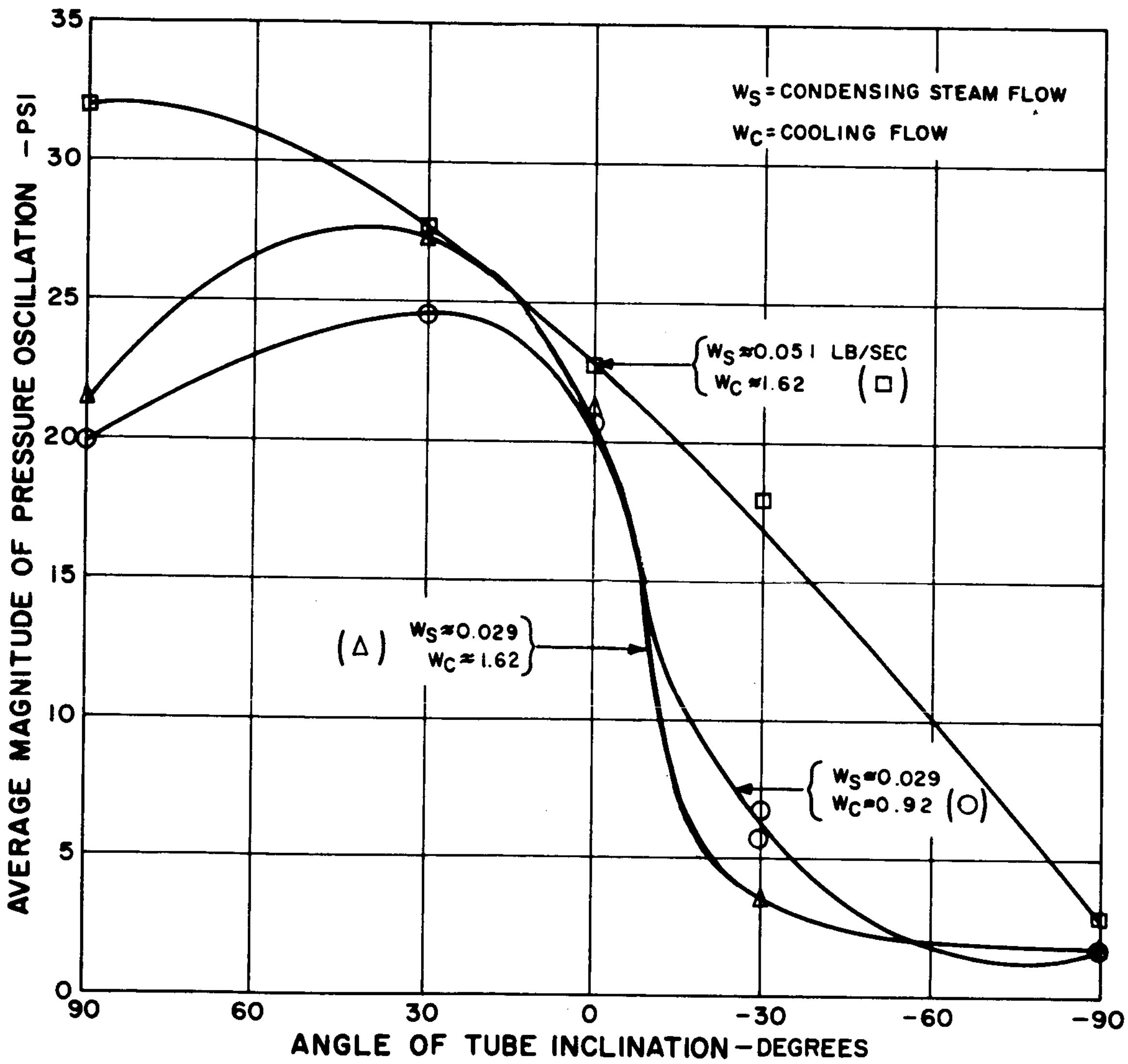


Figure 17 Average Magnitude of Pressure Oscillation at Exit of Condensing Tube vs Angle of Tube Inclination.
Configuration: Single Tube, Constant 0.43-Inch Inside Diameter
Static Pressure at Tube Inlet ≈ 50 psia

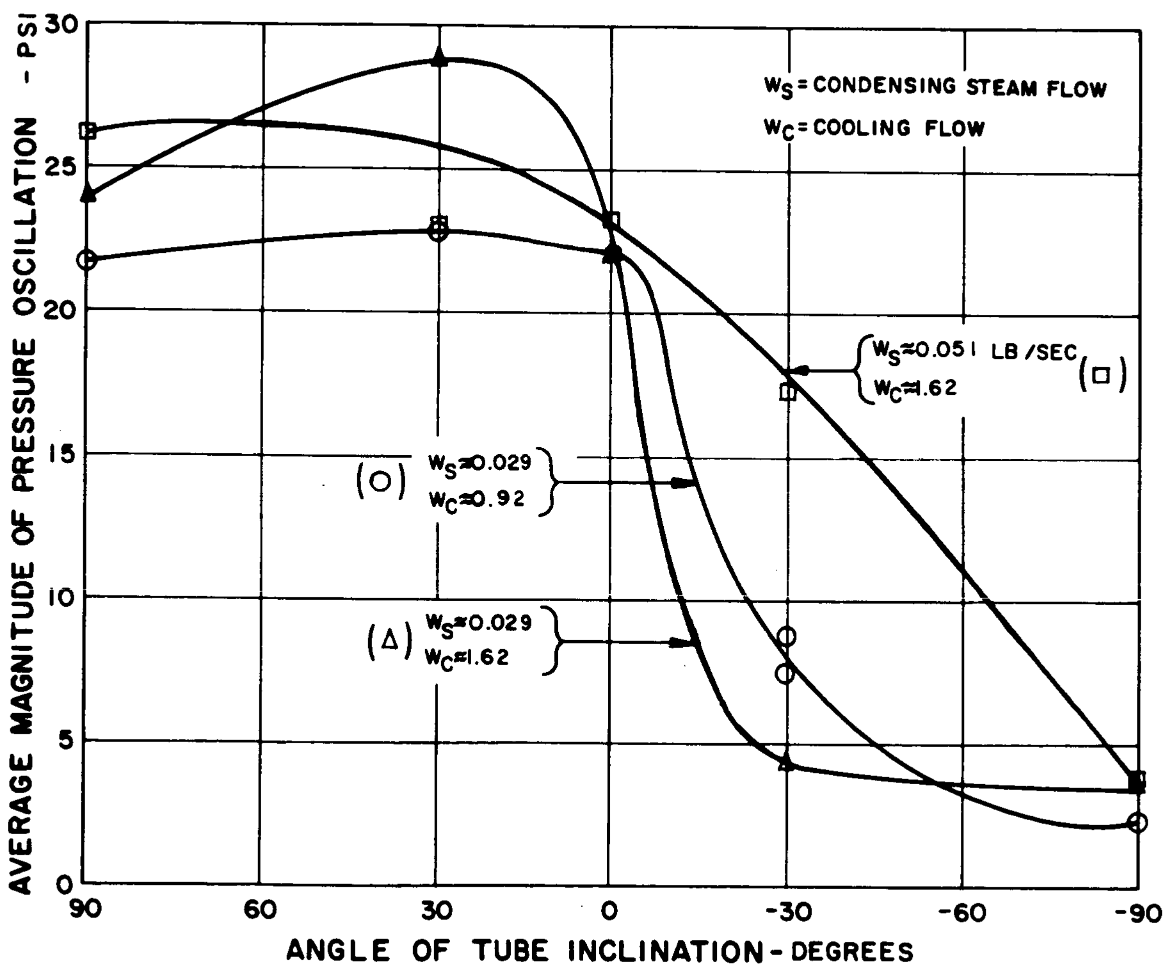


Figure 18 Average Magnitude of Pressure Oscillation at Inlet of Condensing Tube vs Angle of Tube Inclination.
Configuration: Single Tube, Constant 0.43-Inch Inside Diameter
Static Pressure at Tube Inlet ≈ 50 psia

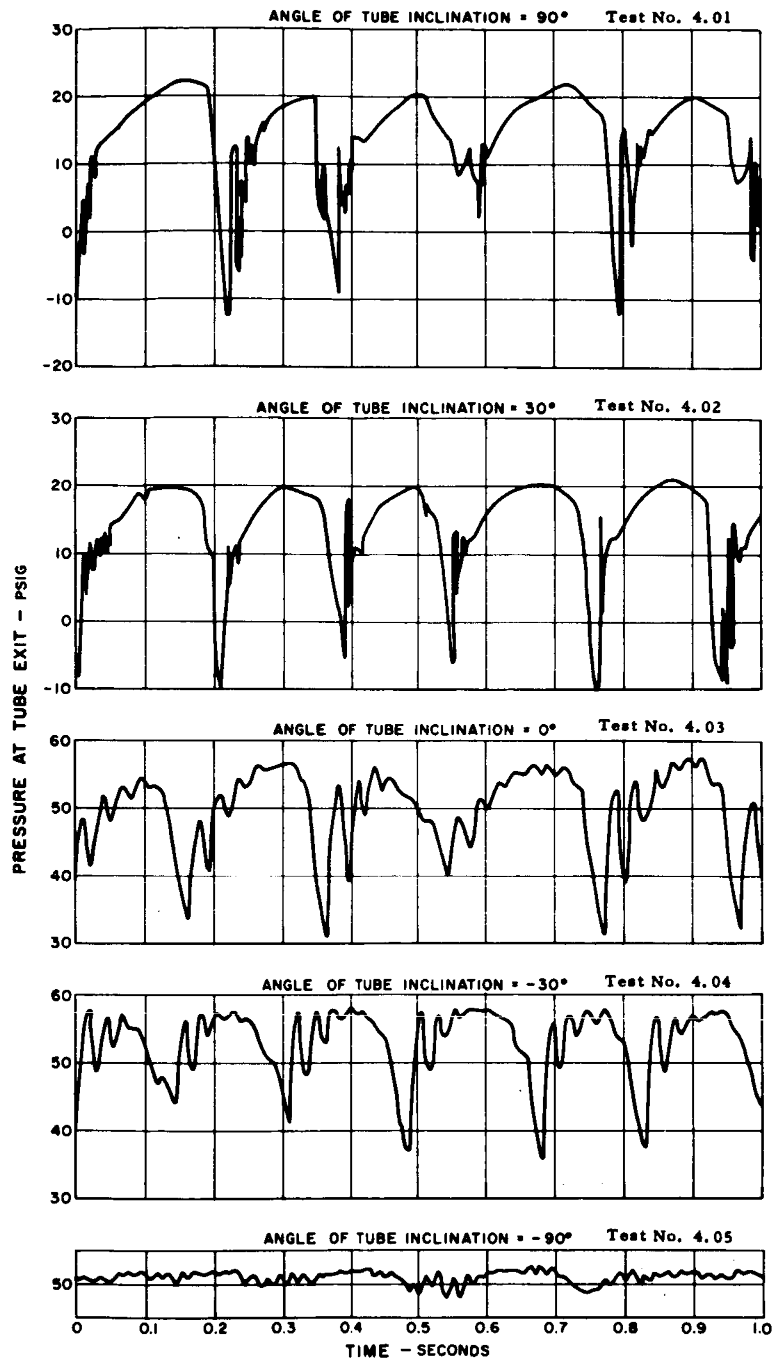


Figure 19 Typical Curves of Tube Exit Pressure vs Time for Various Angles of Tube Inclination.

Configuration: Single Tube, Constant 0.43-Inch Inside Diameter

Conditions:

1. Condensing Steam Flow $W_s \approx 0.050$ lb/sec
2. Cooling Flow $W_c = 1.62$ lb/sec
3. Static Pressure at Tube Inlet $\approx$ 50 psia

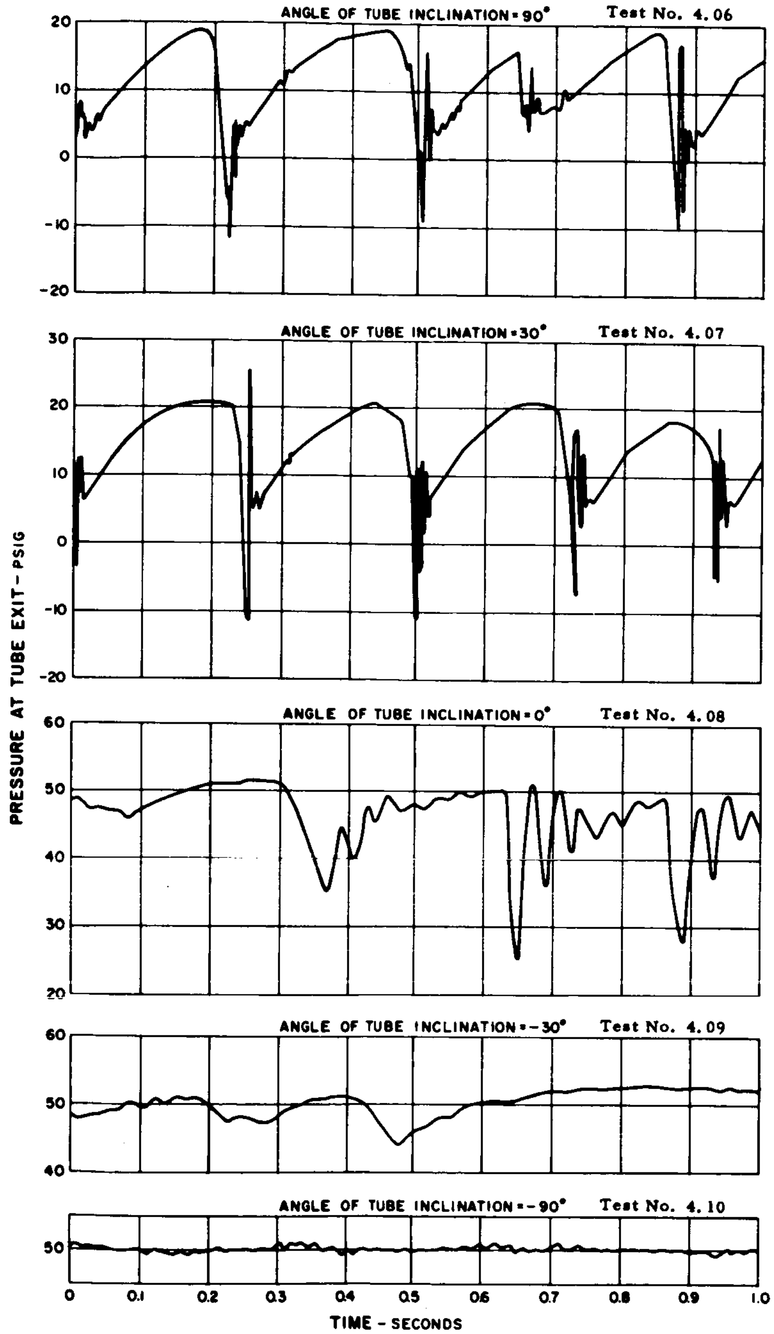


Figure 20 Typical Curves of Tube Exit Pressure vs Time for Various Angles of Tube Inclination.

Configuration: Single Tube, Constant 0.43-Inch Inside Diameter

Conditions:

1. Condensing Steam Flow $W_s \approx 0.029$ lb/sec
2. Cooling Flow $W_c = 1.61$ lb/sec
3. Static Pressure at Tube Inlet $\approx$ 50 psia

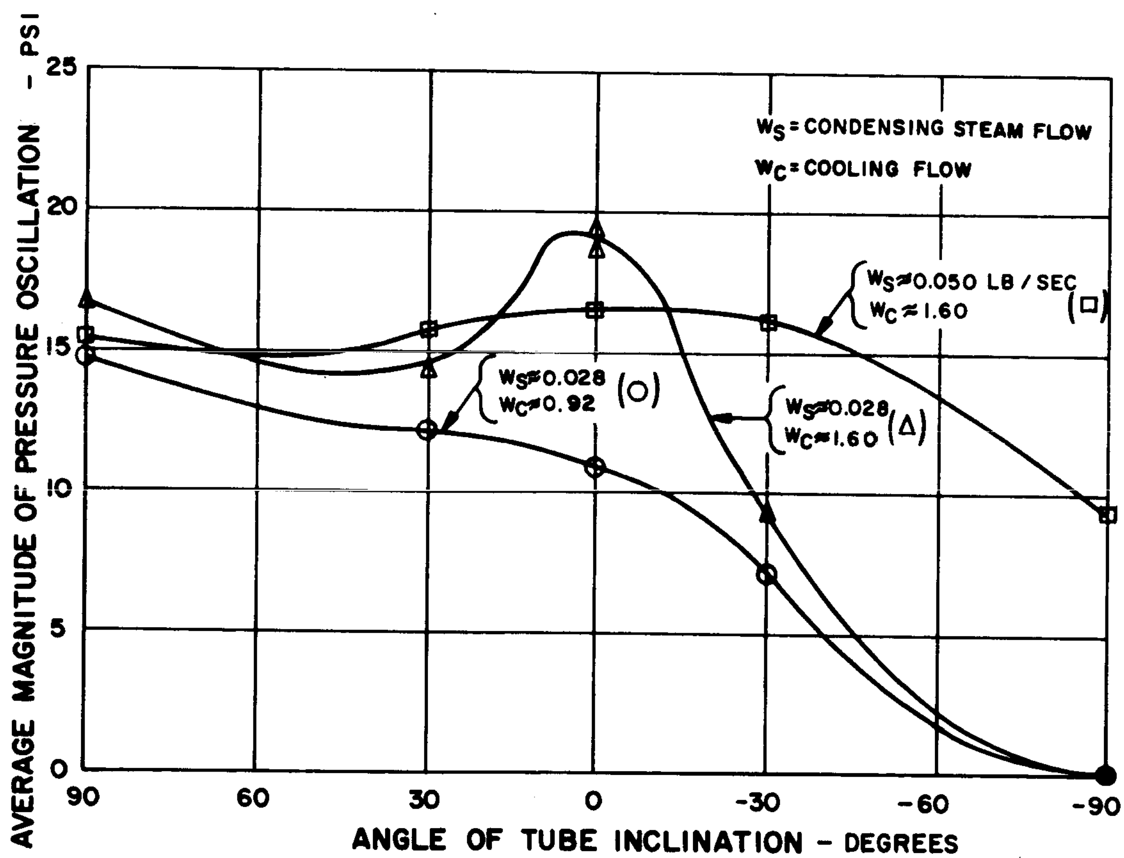


Figure 21 Average Magnitude of Pressure Oscillation at Exit of Condensing Tube vs Angle of Tube Inclination.
Configuration: Single Tube, Constant 0.43-Inch Inside Diameter with Swirler Insert
Static Pressure at Tube Inlet ≈ 50 psia

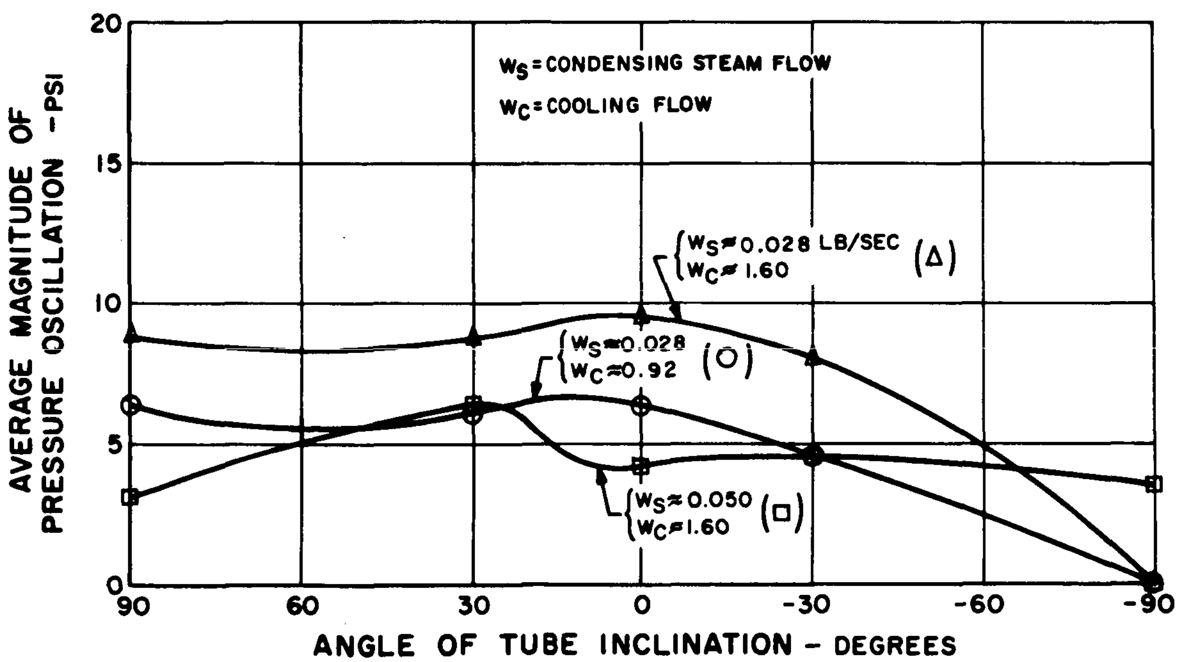


Figure 22 Average Magnitude of Pressure Oscillation at Inlet of Condensing Tube vs Angle of Tube Inclination.
Configuration: Single Tube, Constant 0.43-Inch Inside Diameter with Swirler Insert
Static Pressure at Tube Inlet ≈ 50 psia

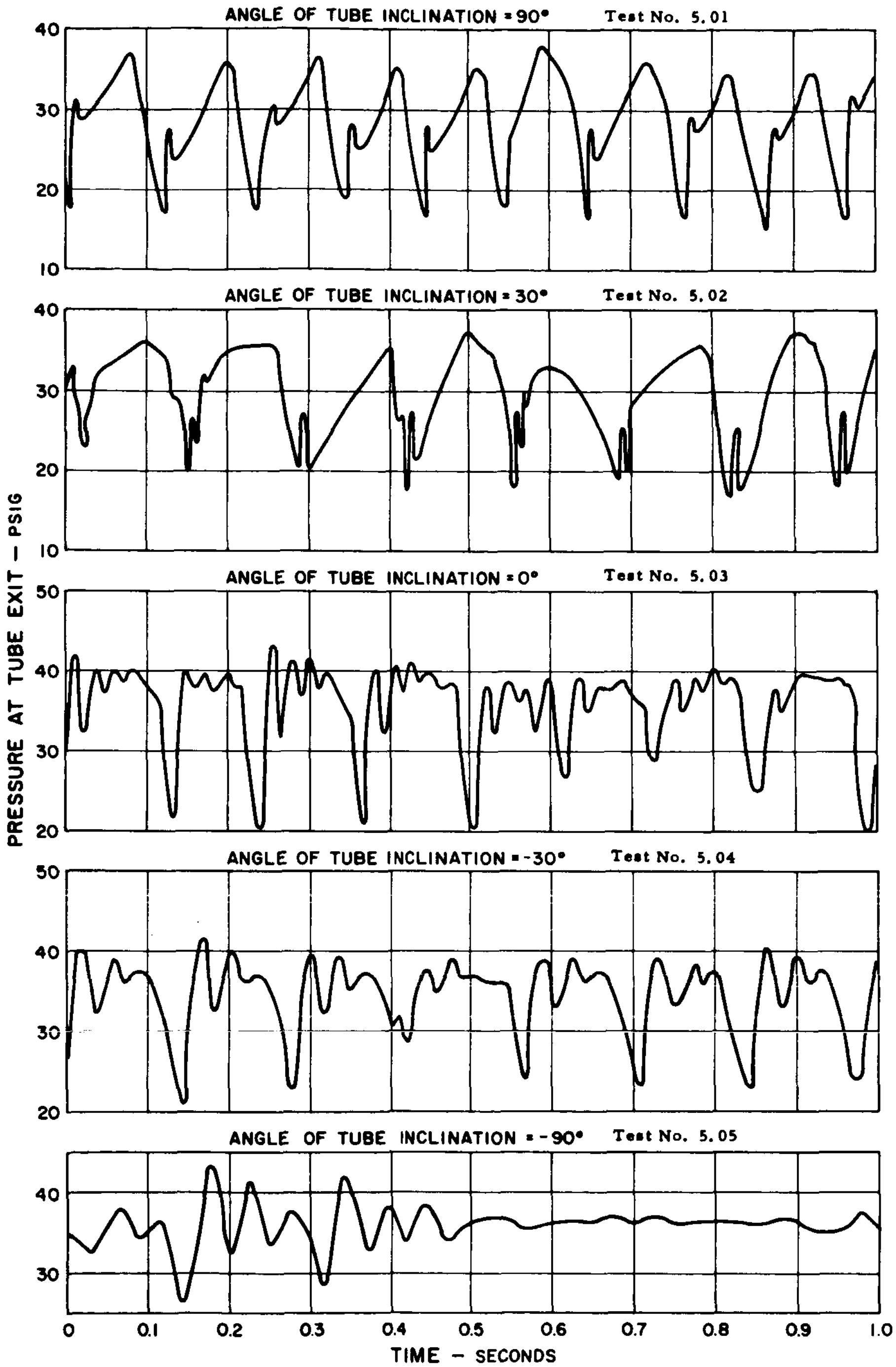


Figure 23 Typical Curves of Tube Exit Pressure vs Time for Various Angles of Tube Inclination.

Configuration: Single Tube, Constant 0.43-Inch Inside Diameter with Swirler

Conditions:
1. Condensing Steam Flow $W_s \approx 0.050$ lb/sec
2. Cooling Flow $W_C \approx 1.60$ lb/sec
3. Static Pressure at Tube Inlet $\approx$ 50 psia

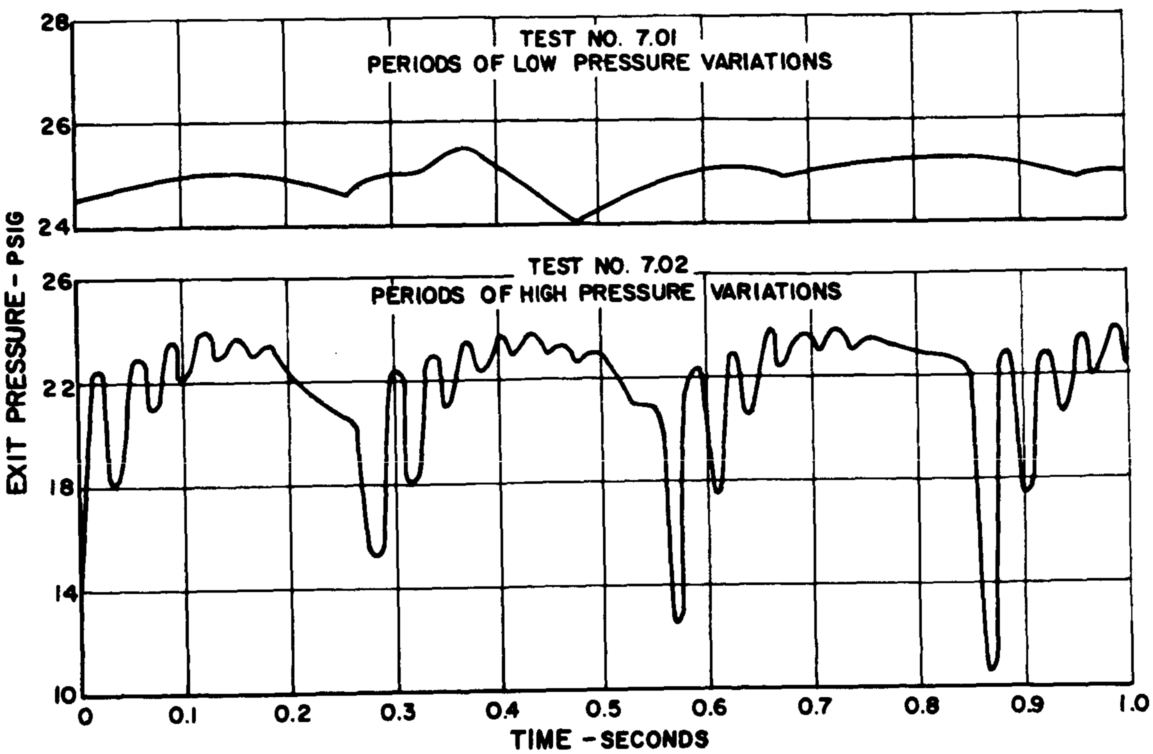


Figure 24 Typical Curves of Tube Exit Pressure vs Time For Different Periods during Test

Configuration: Single Tube. Constant 0.43-Inch Inside Diameter with Slotted Tubular Insert (3/16-Inch Outside Diameter)

Conditions:
1. Condensing Steam Flow W_s = 0.028 lb/sec
2. Cooling Flow W_c = 1.6 lb/sec
3. Angle of Tube Inclination = 0°
4. Static Pressure at Tube Inlet ≈ 50 psia

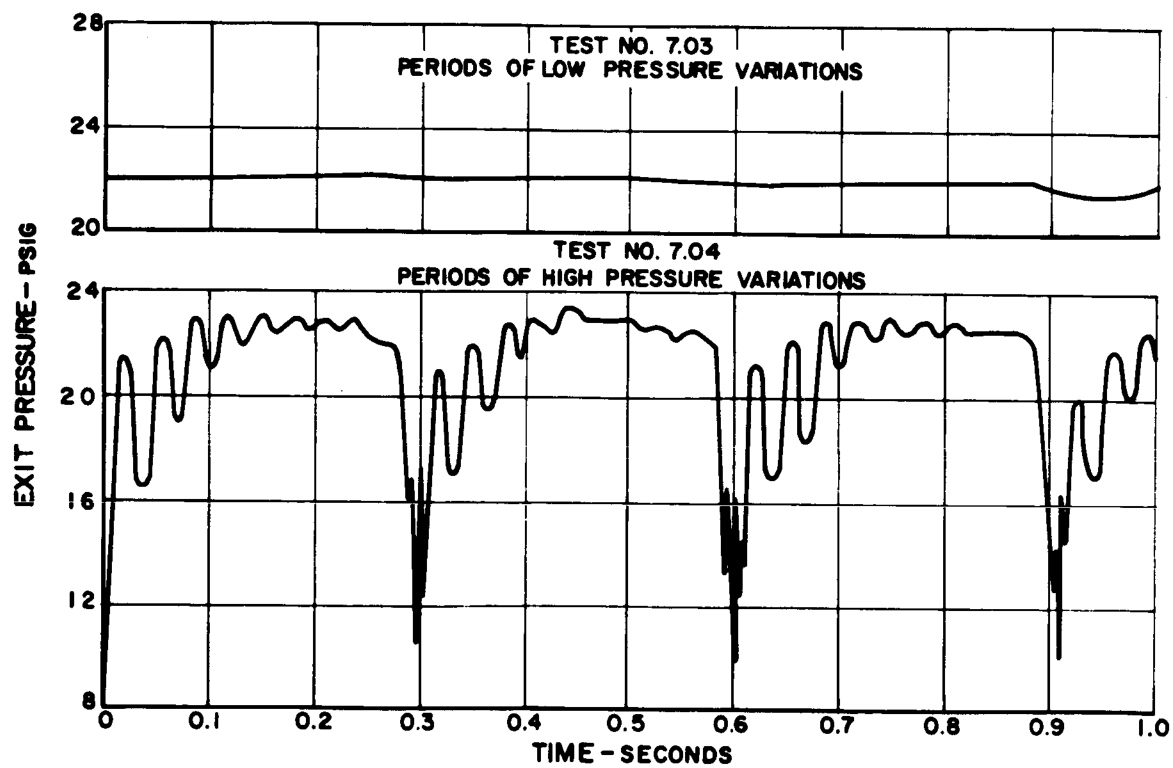


Figure 25 Typical Curves of Tube Exit Pressure vs Time for Different Periods during Test

Configuration: Single Tube. Constant 0.43-Inch Inside Diameter with Slotted Tubular Insert (3/16-Inch Outside Diameter)

Conditions:
1. Condensing Steam Flow W_s = 0.021 lb/sec
2. Cooling Flow W_c = 1.6 lb/sec
3. Angle of Tube Inclination = 0°
4. Static Pressure at Tube Inlet ≈ 50 psia

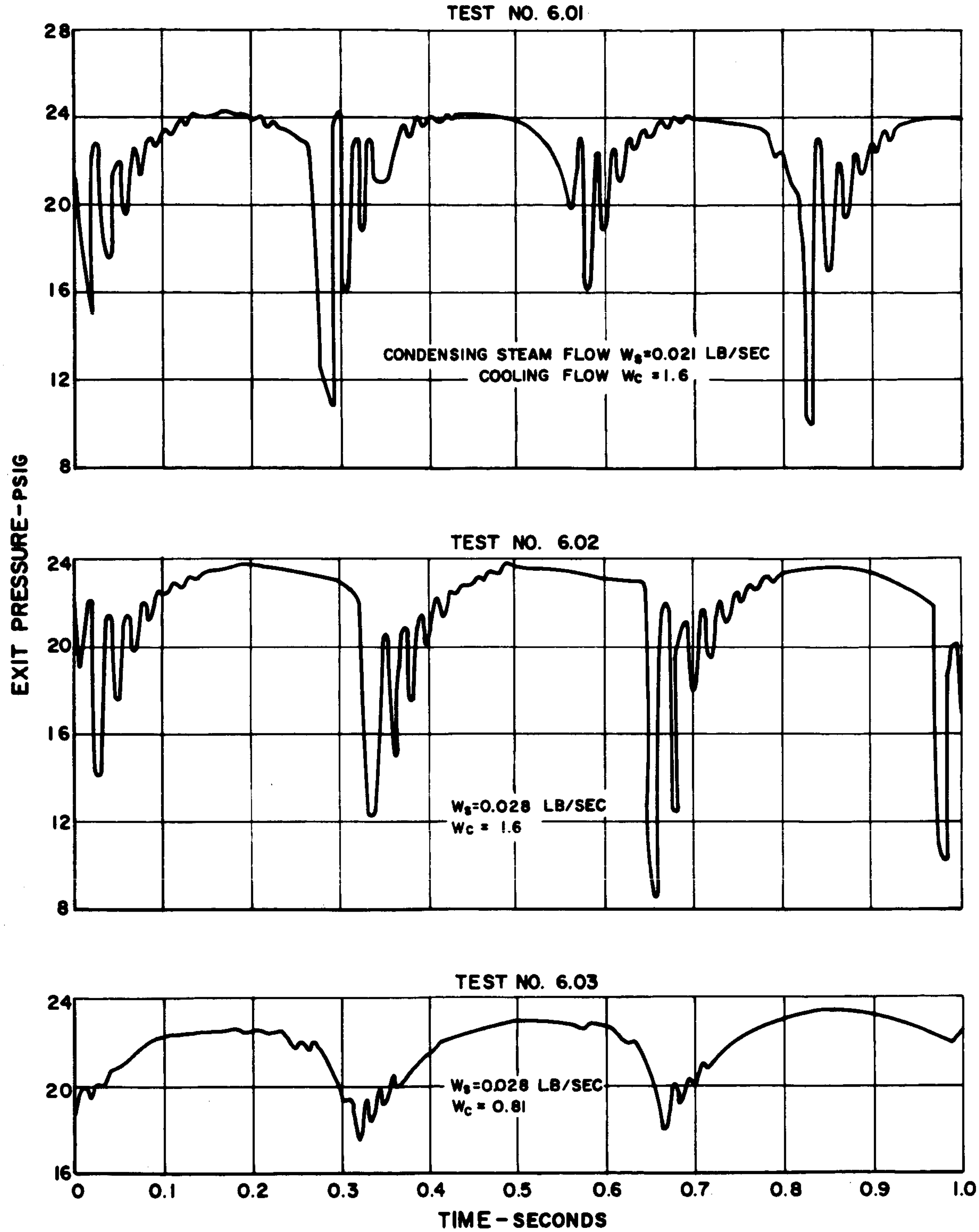


Figure 26 Typical Curve of Tube Exit Pressure vs Time
Configuration: Single Tube. Constant 0.43-Inch Inside Diameter with Nonslotted Tubular Insert (3/16-Inch Outside Diameter). Angle of Tube Inclination = 0°

Static Pressure at Tube Inlet ≈ 50 psia

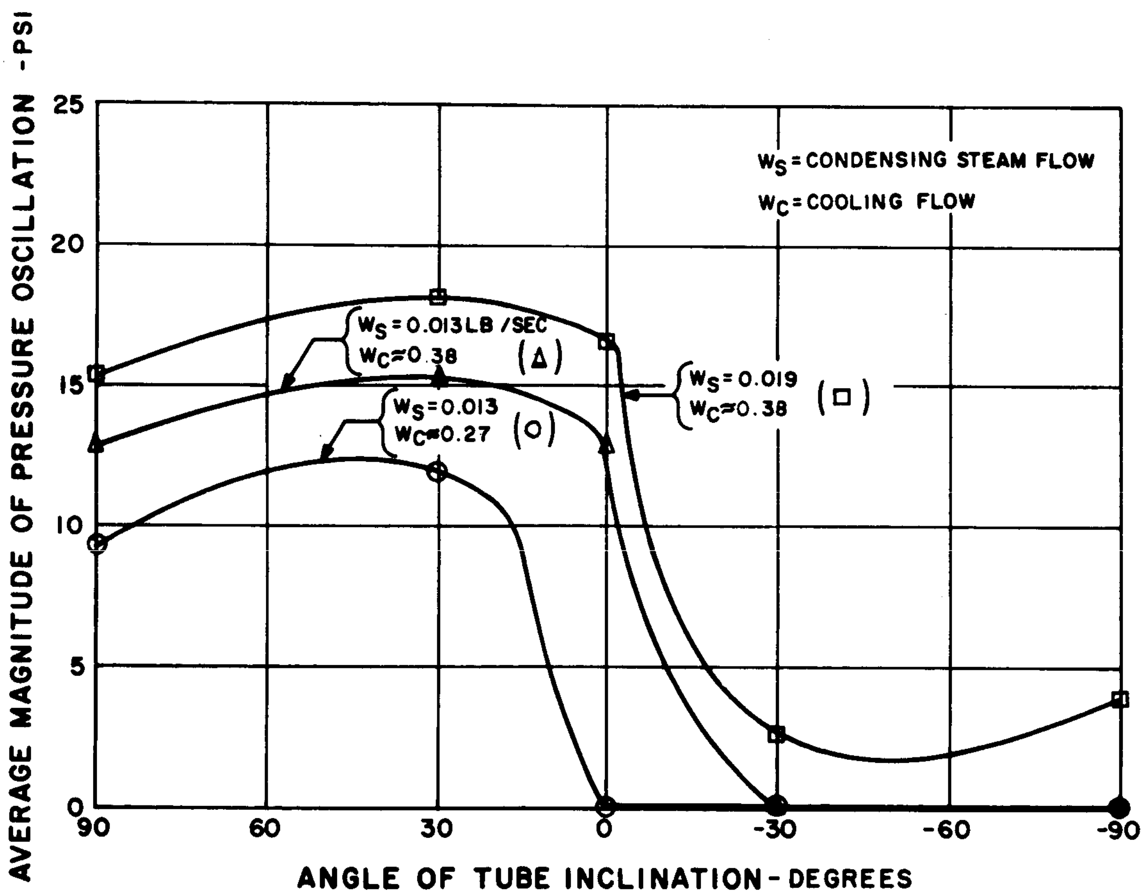


Figure 27 Average Magnitude of Pressure Oscillation at Exit of Condensing Tube vs Angle of Tube Inclination.
Configuration: Single Tapered Tube
Inlet Inside Diameter 0.50 Inch
Exit Inside Diameter 0.1875 Inch
Length 43.0 Inches
Static Pressure at Tube Inlet ≈ 50 psia

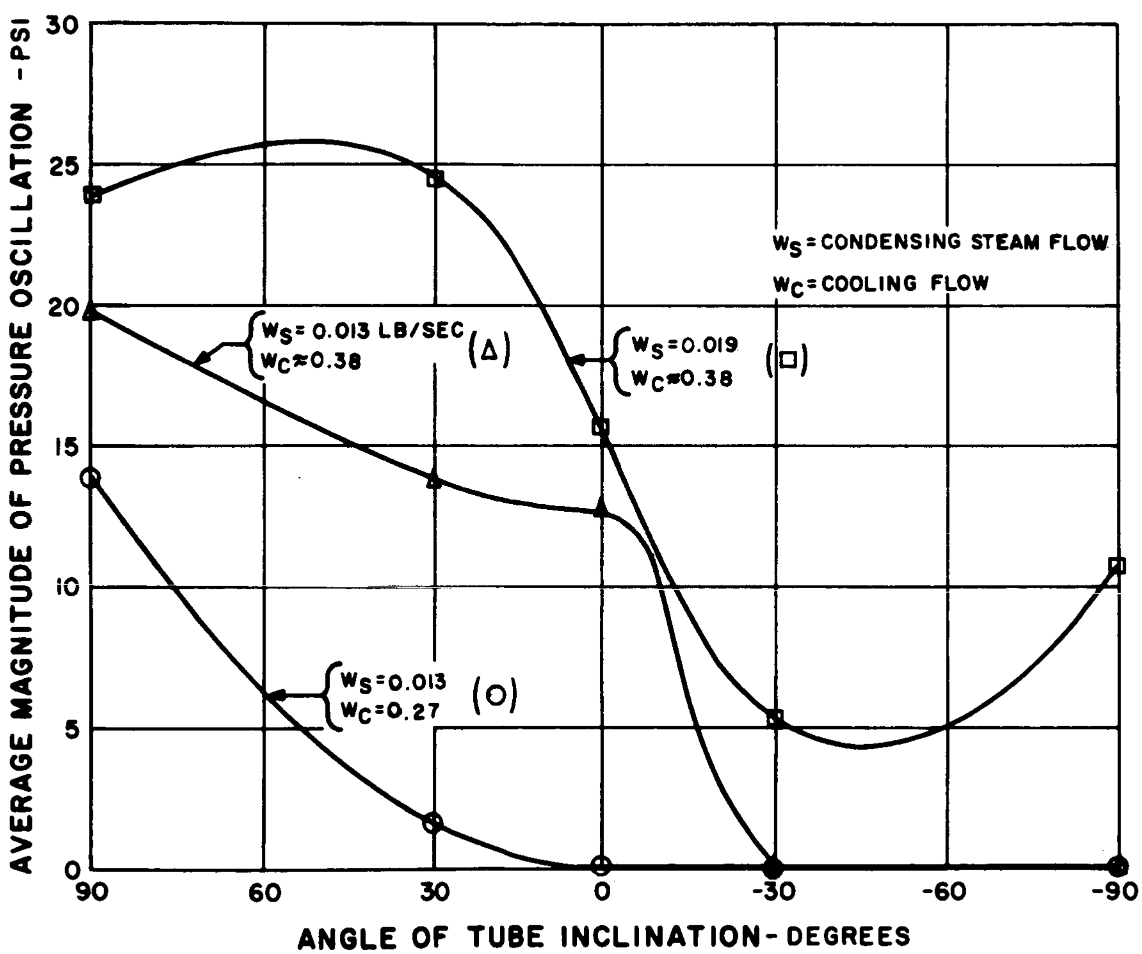


Figure 28 Average Magnitude of Pressure Oscillation at Inlet of Condensing Tube vs Angle of Tube Inclination.
Configuration: Single Tapered Tube
Inlet Inside Diameter 0.50 Inch
Exit Inside Diameter 0.1875 Inch
Length 43.0 Inches
Static Pressure at Tube Inlet $\approx$ 50 psia

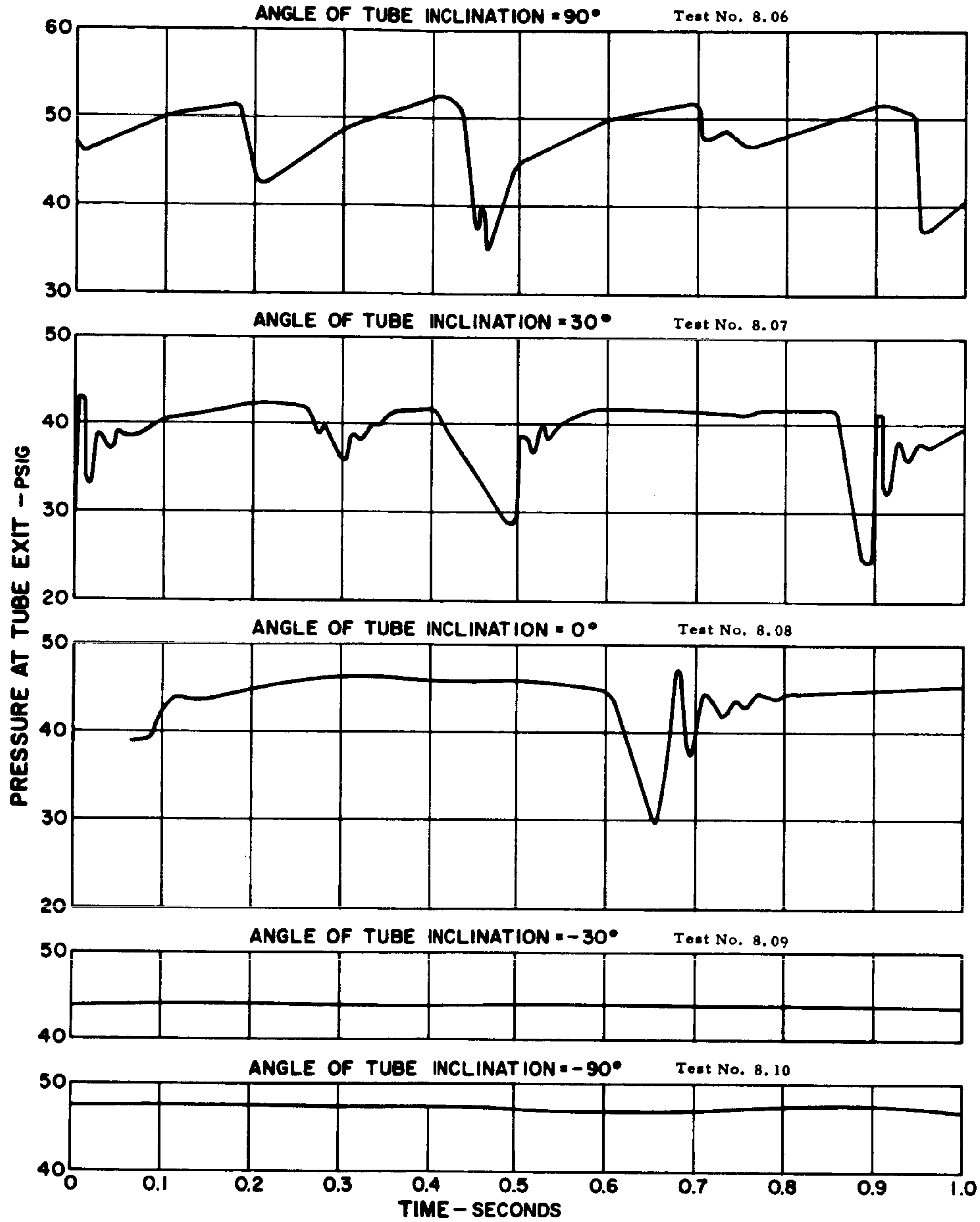


Figure 29 Typical Curves of Tube Exit Pressure vs Time for Various Angles of Tube Inclination.

Configuration: Single Tapered Tube
Inlet Inside Diameter 0.50 Inch
Exit Inside Diameter 0.1875 Inch
Length 43.0 Inches

Conditions:
1. Condensing Steam Flow $W_s = 0.013$ lb/sec
2. Cooling Flow $W_c \approx 0.37$ lb/sec
3. **Static Pressure at Tube Inlet $\approx$ 50 psia**

Conditions:

1. Cooling Arrangement across Tubes
2. No Orifices
3. Tube Axes Horizontal, Tubes Stacked in Horizontal Plane
4. Condensing Steam Flow Rate per Tube prior to Shutoff = 0.021 lb/sec
5. Cooling Flow Rate per Tube prior to Shutoff = 0.81 lb/sec
6. Large Inlet Header

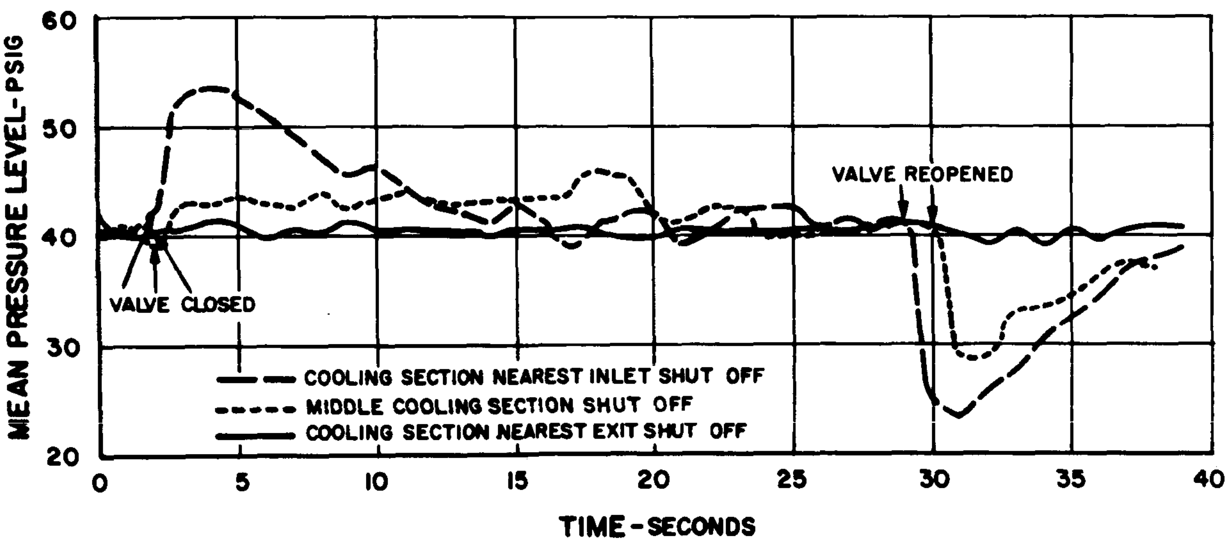


Figure 30 Mean Pressure Level vs Time Showing Effects of Shutting Off Coolant to Different Cooling Sections. Tests No. 9.07, 9.08, and 9.09

Conditions:
1. Cooling Arrangement across Tubes
2. No Orifices
3. Tube Axes Horizontal, Tubes Stacked in Horizontal Plane
4. Condensing Steam Flow Rate per Tube prior to Shutoff = 0.021 lb/sec
5. Cooling Flow Rate per Tube prior to Shutoff = 0.81 lb/sec
6. Large Inlet Header

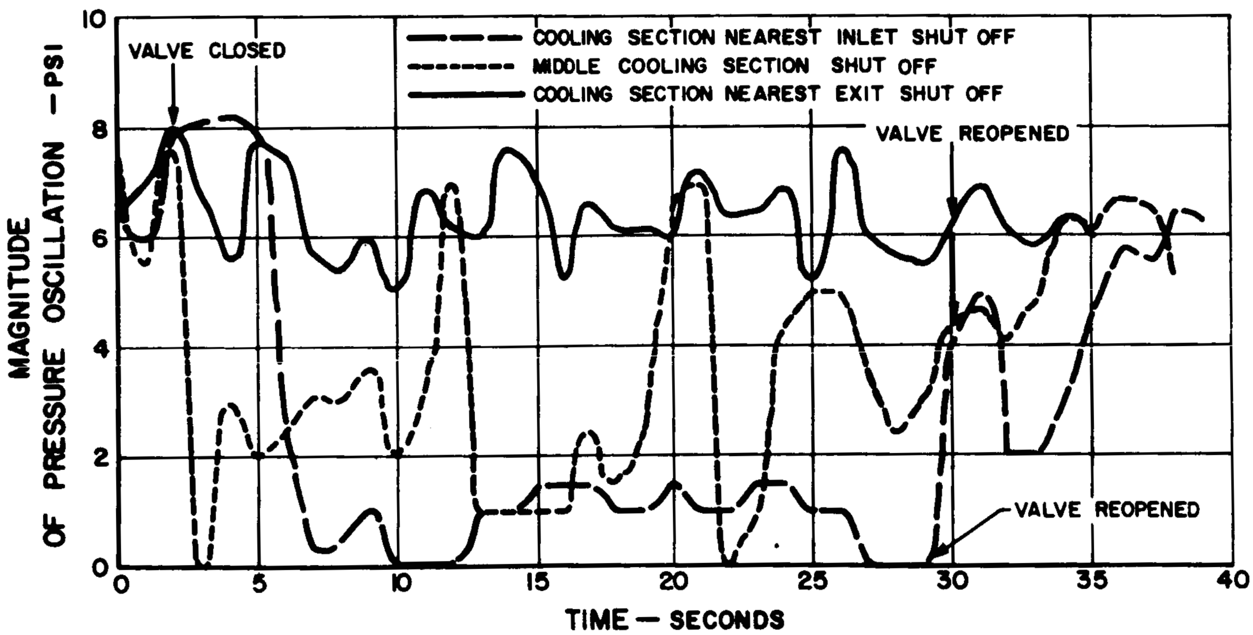


Figure 31 Magnitude of Pressure Oscillation at Exit Header vs Time Showing Effects of Shutting Off Coolant to Different Cooling Sections. Tests Nos. 9.07, 9.08, and 9.09

Conditions:
1. Cooling Arrangement across Tubes
2. No Orifices
3. Tube Axes Horizontal, Tubes Stacked in Horizontal Plane
4. Condensing Steam Flow Rate per Tube prior to Shutoff = 0.021 lb/sec
5. Cooling Flow Rate per Tube prior to Shutoff = 0.81 lb/sec
6. Large Inlet Header

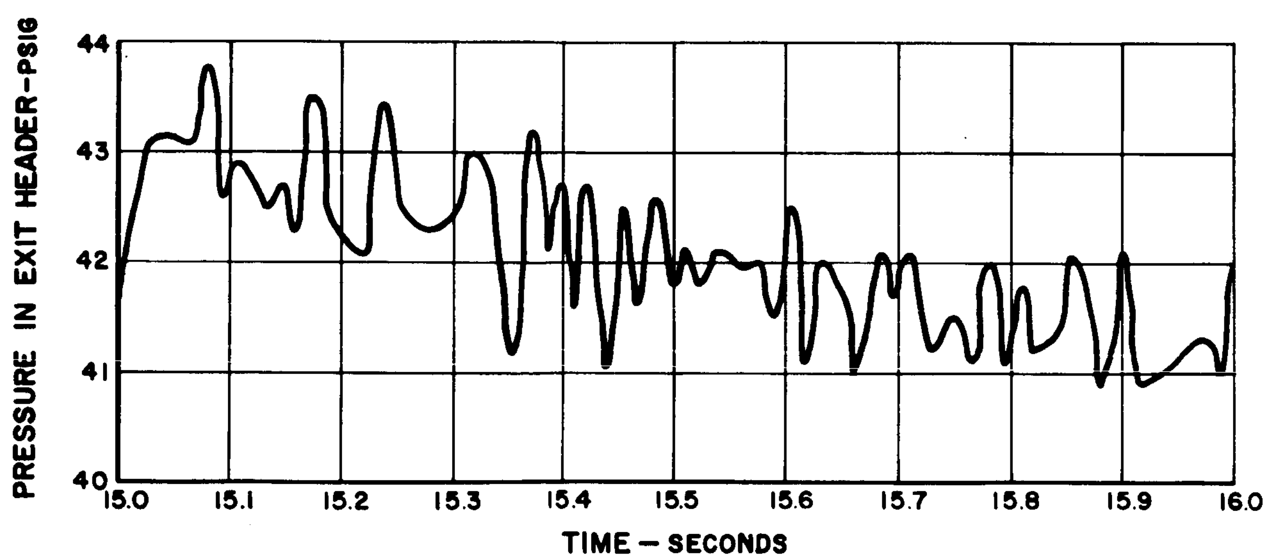


Figure 32 Typical Curve of Pressure in Exit Header vs Time during Period Coolant to Cooling Sections nearest Inlet Header is Shut Off. Test No. 9.07

Conditions:
1. Cooling Arrangement across Tubes
2. No Orifices
3. Tube Axes Horizontal, Tubes Stacked in Horizontal Plane
4. Condensing Steam Flow Rate per Tube prior to Shutoff = 0.021 lb/sec
5. Cooling Flow Rate per Tube prior to Shutoff = 0.81 lb/sec
6. Large Inlet Header

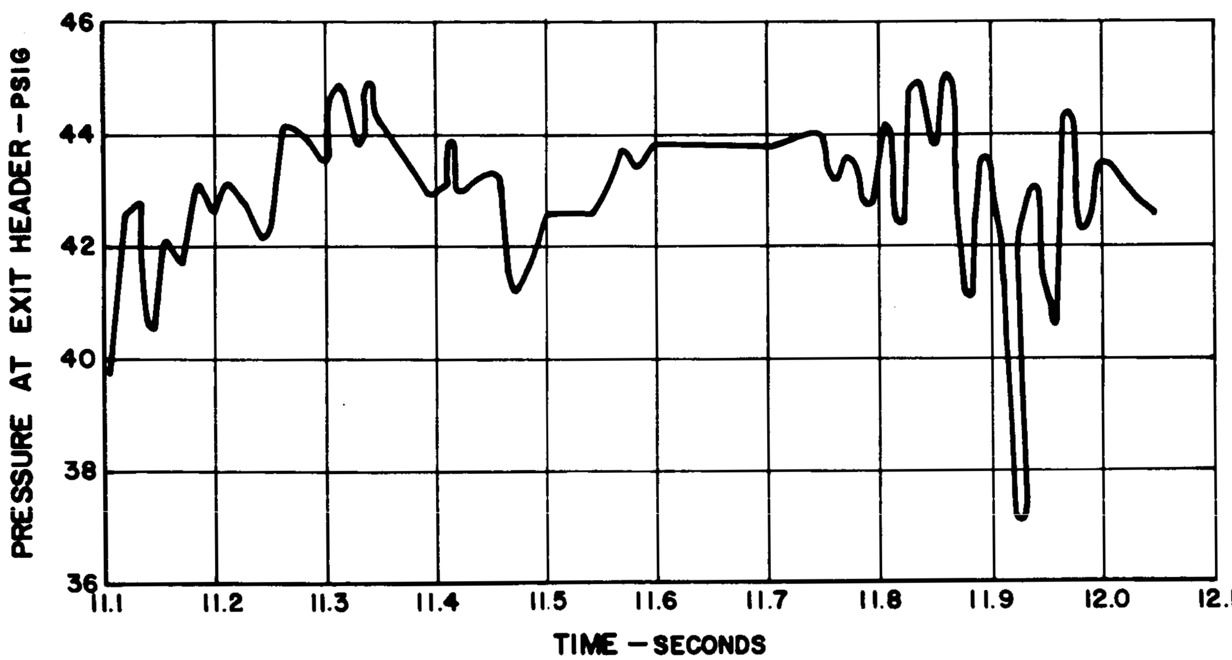
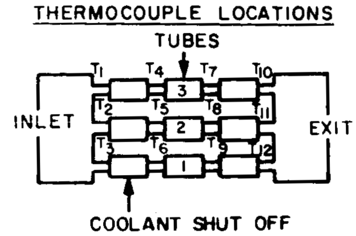


Figure 33 Typical Curve of Pressure in Exit Header vs Time during Period Coolant to Middle Cooling Sections is Shut Off. Test No. 9.08

Conditions:

1. Cooling Arrangement across Tubes
2. No Orifices
3. Tube Axes Horizontal, Tubes Stacked in Horizontal Plane
4. Condensing Steam Flow Rate per Tube prior to Shutoff = 0.021 lb/sec
5. Cooling Flow Rate per Tube prior to Shutoff = 0.81 lb/sec
6. Cooling Sections **Shut Off** - Nearest Inlet
7. Large Inlet Header



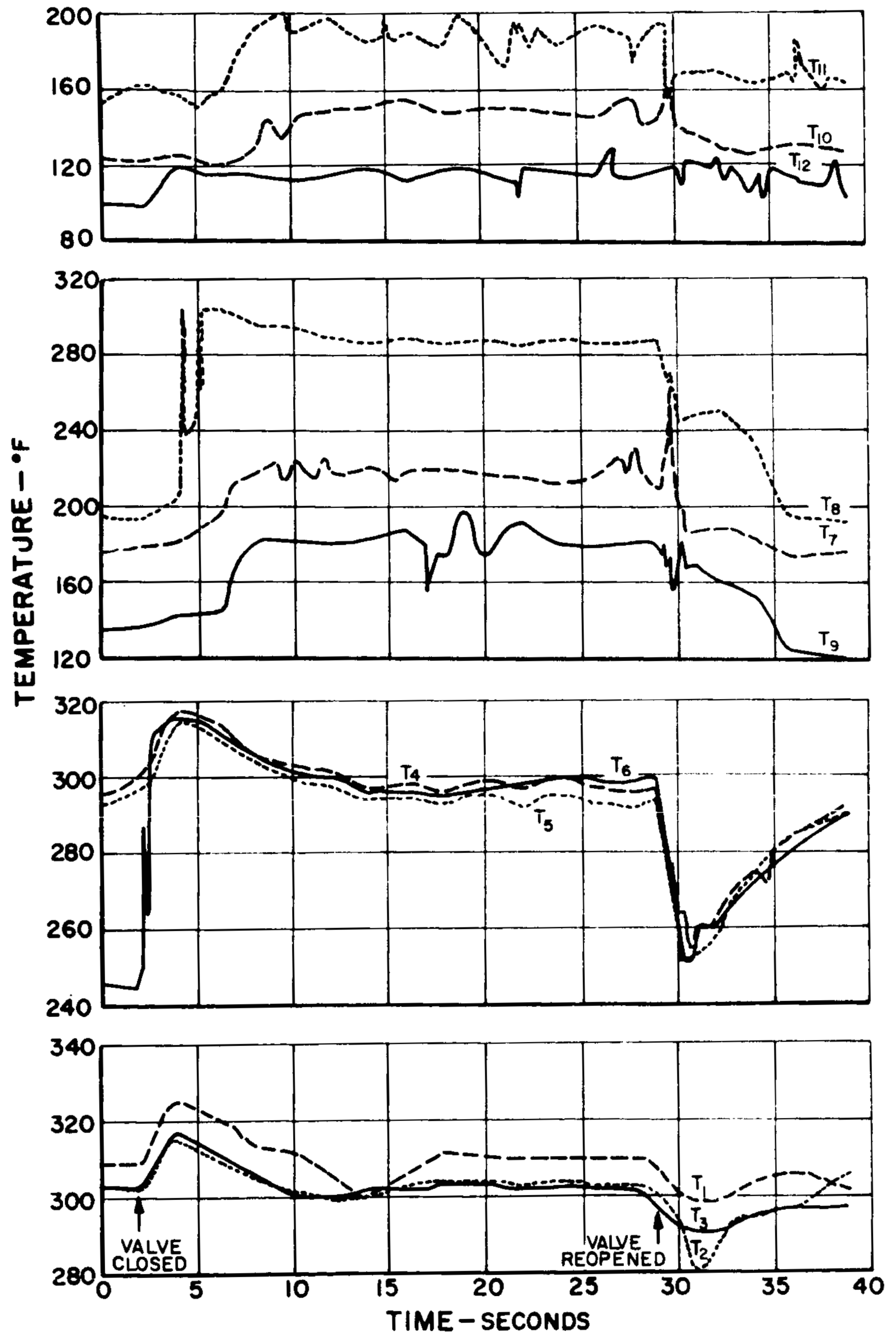


Figure 34 Condensing Fluid Mean Temperature at Various Locations vs Time. Test No. 9.07

Conditions:
1. Cooling Arrangement across Tubes
2. No Orifices
3. Tube Axes Horizontal, Tubes Stacked in Horizontal Plane
4. Condensing Steam Flow Rate per Tube prior to Shutoff = 0.021 lb/sec
5. Cooling Flow Rate per Tube prior to Shutoff = 0.81 lb/sec
6. Cooling Sections Shut Off - Middle
7. Large Inlet Header

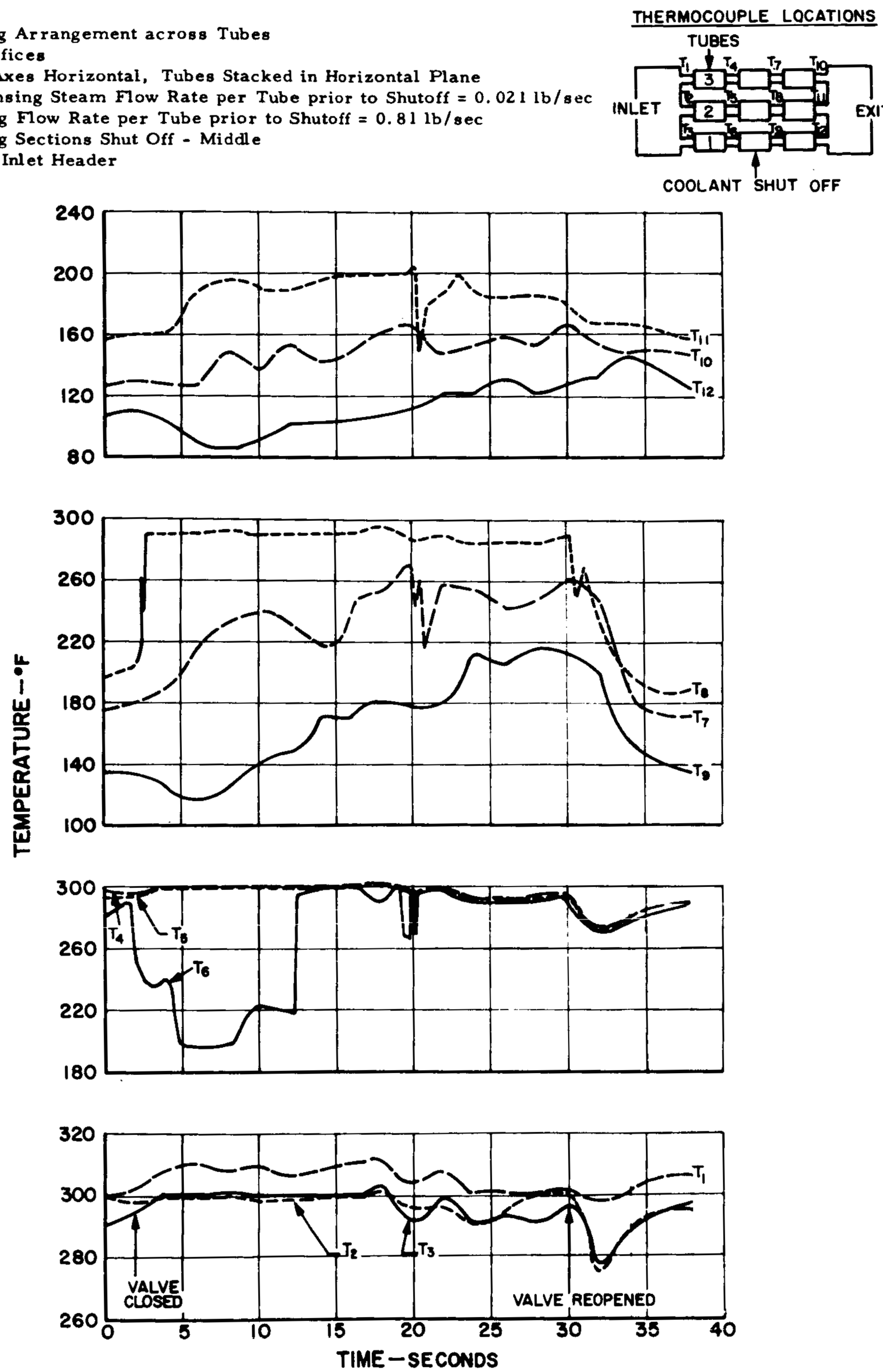


Figure 35 Condensing Fluid Mean Temperature at Various Locations vs Time. Test No. 9.08

Conditions:

1. Cooling Arrangement across Tubes
2. No Orifices
3. Tube Axes Horizontal, Tubes Stacked in Horizontal Plane
4. Condensing Steam Flow Rate per Tube prior to Shutoff = 0.021 lb/sec
5. Cooling Flow Rate per Tube prior to Shutoff = 0.81 lb/sec
6. Cooling Sections Shut Off - Nearest Exit
7. Large Inlet Header

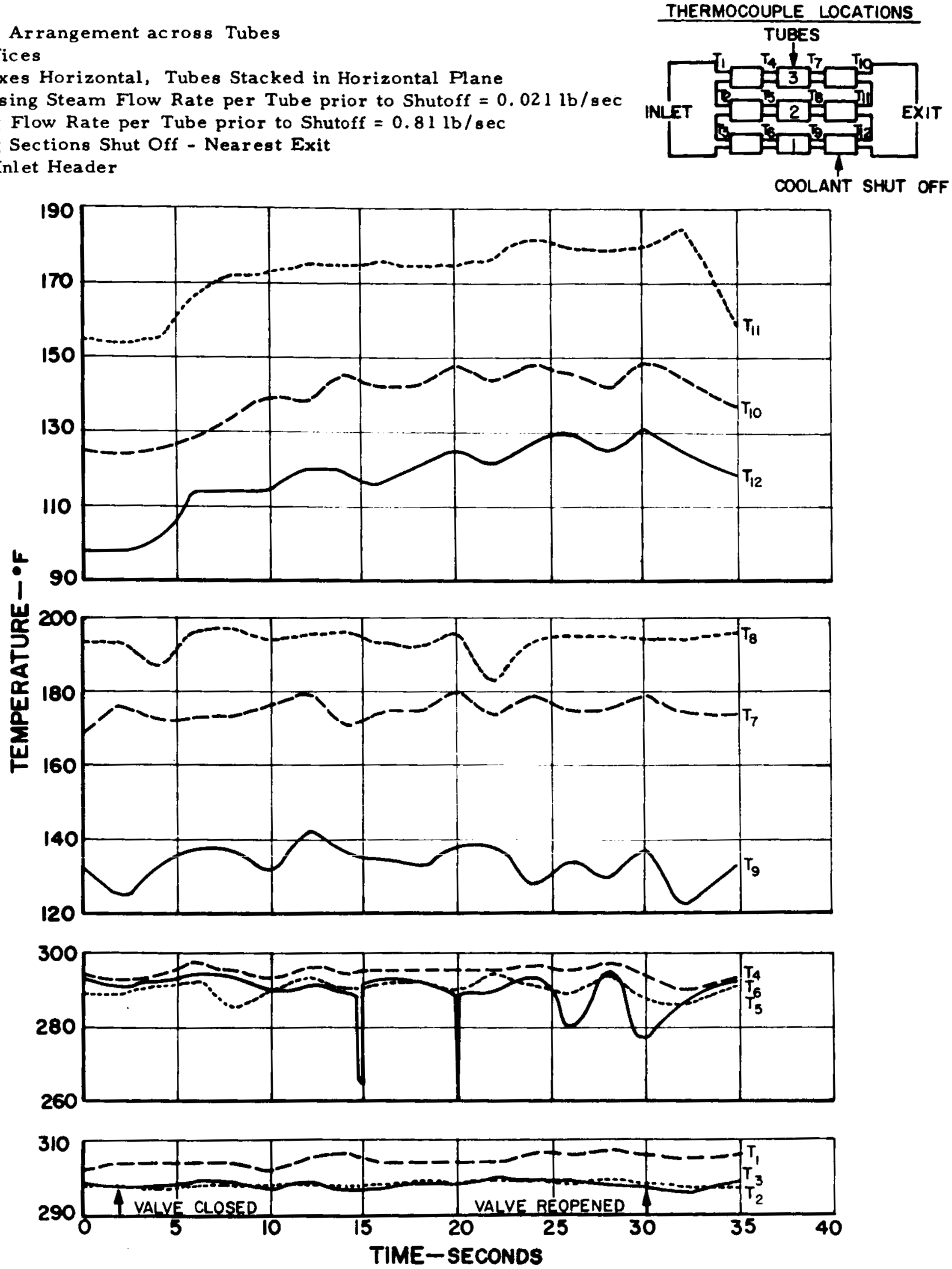


Figure 36 Condensing Fluid Mean Temperature at Various Locations vs Time. Test No. 9.09

Conditions:
1. Cooling Arrangement across Tubes
2. No Orifices
3. Tube Axes Horizontal, Tubes Stacked in Vertical Plane
4. Condensing Steam Flow Rate per Tube prior to Shutoff = 0.022 lb/sec
5. Cooling Flow Rate per Tube prior to Shutoff = 0.81 lb/sec
6. Large Inlet Header

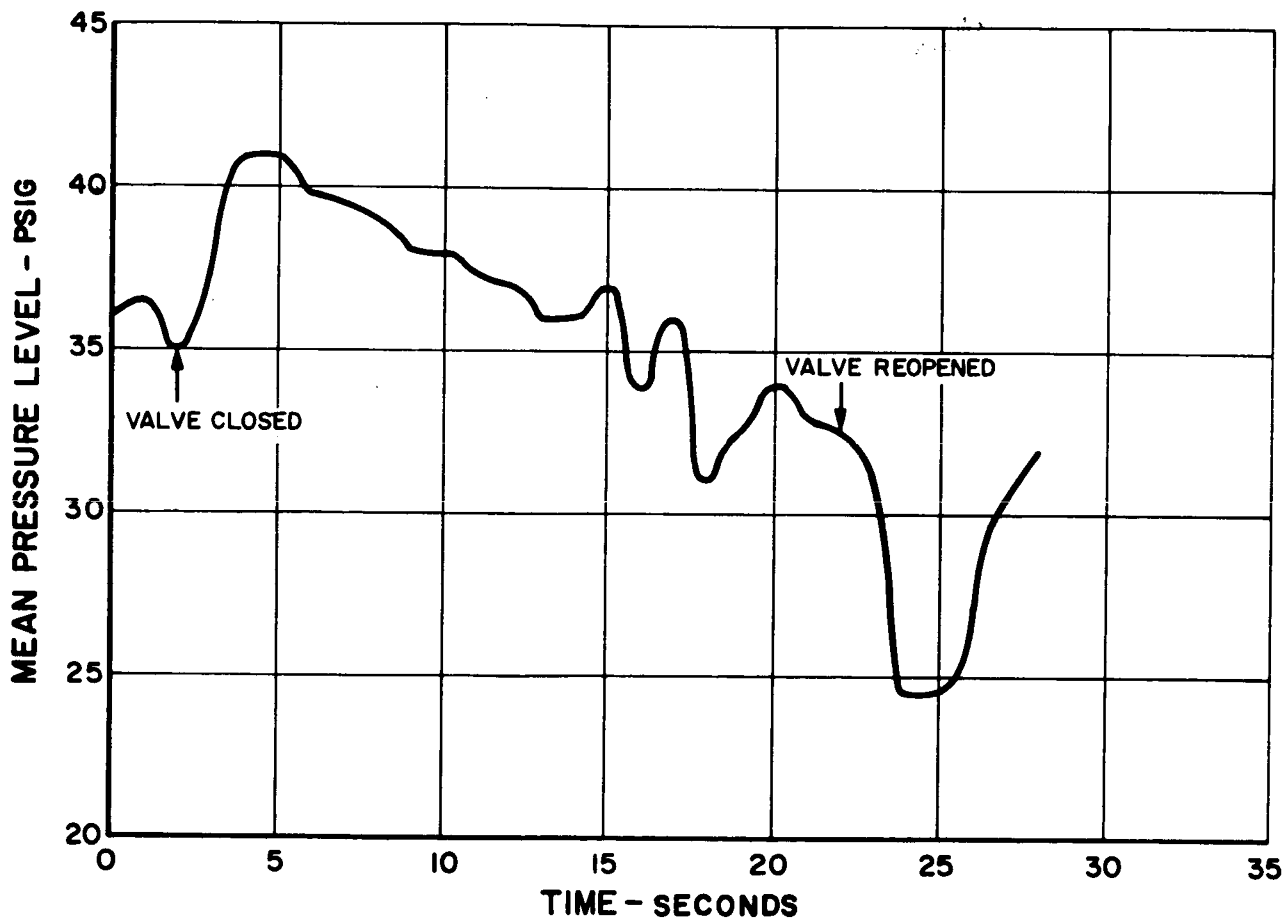


Figure 37 Mean Pressure Level vs Time Showing Effects of Shutting Off Coolant to Middle Cooling Sections. Test No. 9.02

Conditions:
1. Cooling Arrangement across Tubes
2. No Orifices
3. Tube Axes Horizontal, Tubes Stacked in Vertical Plane
4. Condensing Steam Flow Rate per Tube prior to Shutoff = 0.022 lb/sec
5. Cooling Flow Rate per Tube prior to Shutoff = 0.81 lb/sec
6. Large Inlet Header

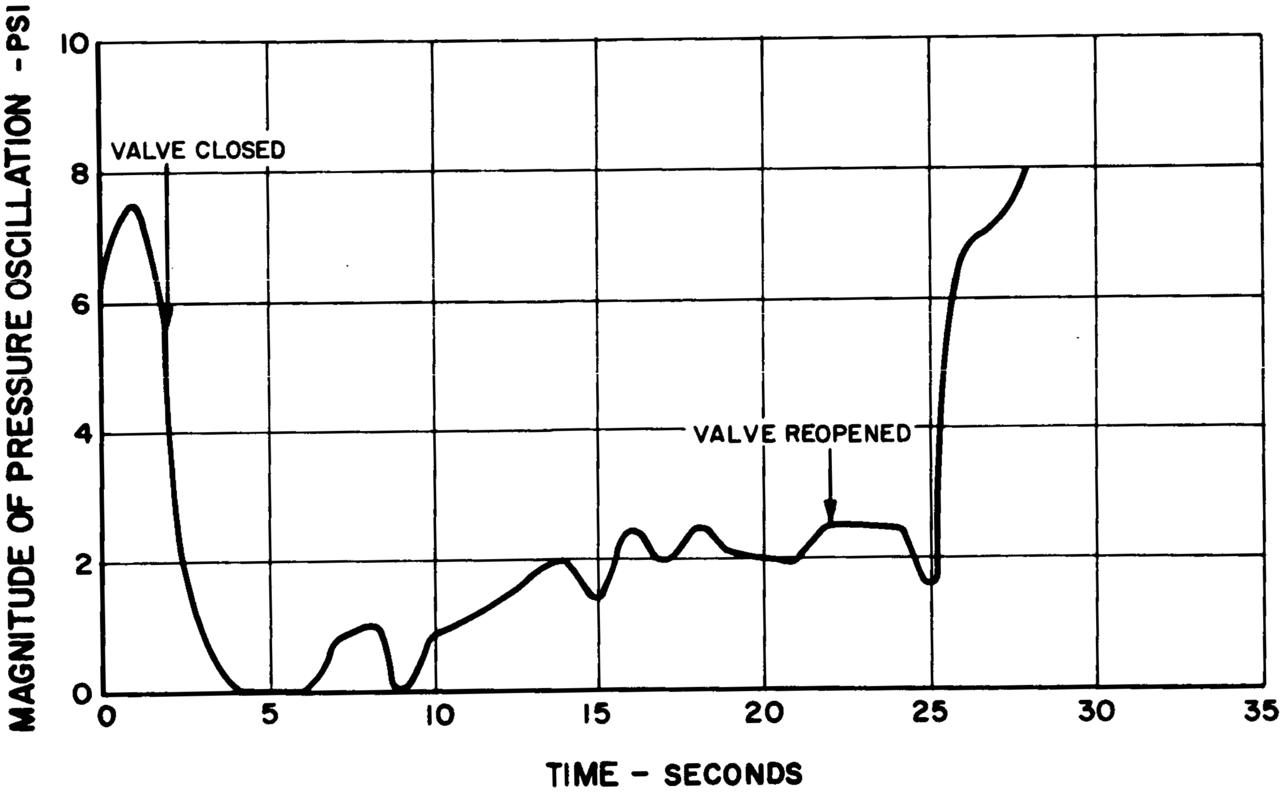
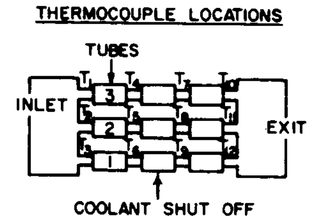


Figure 38 Magnitude of Pressure Oscillation at Exit Header vs Time Showing Effects of Shutting Off Coolant to Middle Cooling Sections. Test No. 9.02

Conditions:
1. Cooling Arrangement across Tubes
2. No Orifices
3. Tube Axes Horizontal, Tubes Stacked in Vertical Plane
4. Condensing Steam Flow Rate per Tube prior to Shutoff = 0.022 lb/sec
5. Cooling Flow Rate per Tube prior to Shutoff = 0.81 lb/sec
6. Cooling Sections **Shut Off**-Middle
7. Large Inlet Header



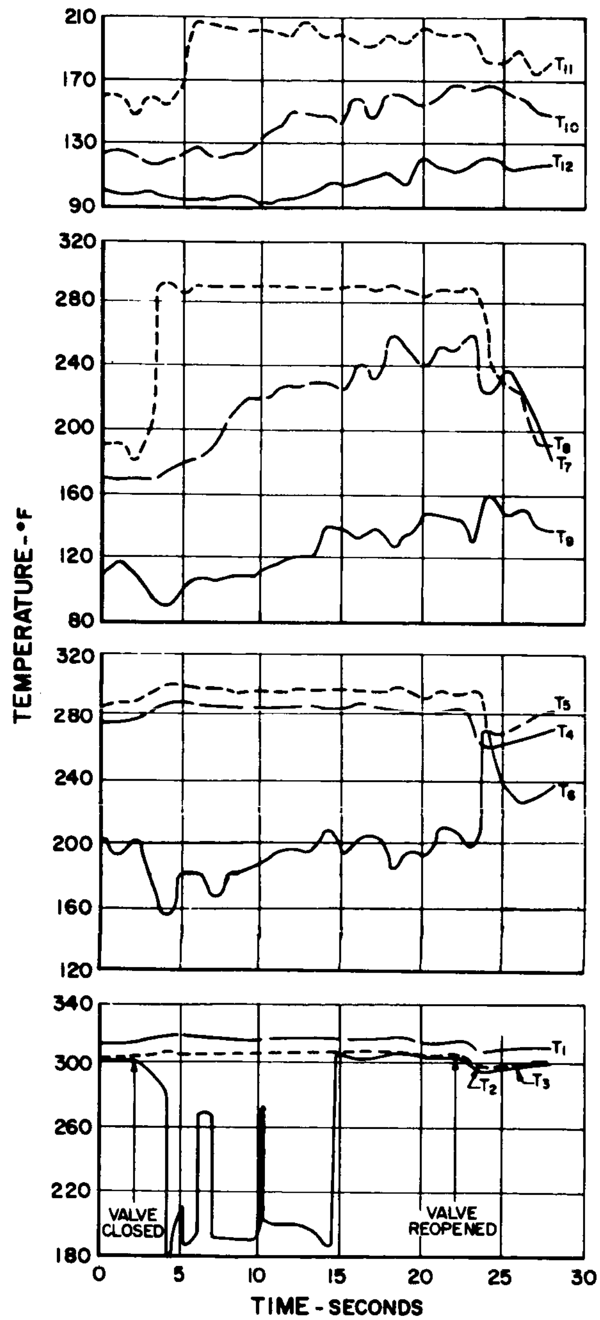


Figure 39 Condensing Fluid Mean Temperature at Various Locations vs Time. Test No. 9.02

Conditions:
1. Cooling Arrangement across Tubes
2. Orifices in Tube Exits
3. Tube Axes Horizontal, Tubes Stacked in Horizontal Plane
4. Condensing Steam Flow Rate per Tube prior to Shutoff = 0.021 lb/sec
5. Cooling Flow Rate per Tube prior to Shutoff = 0.81 lb/sec
6. Large Inlet Header

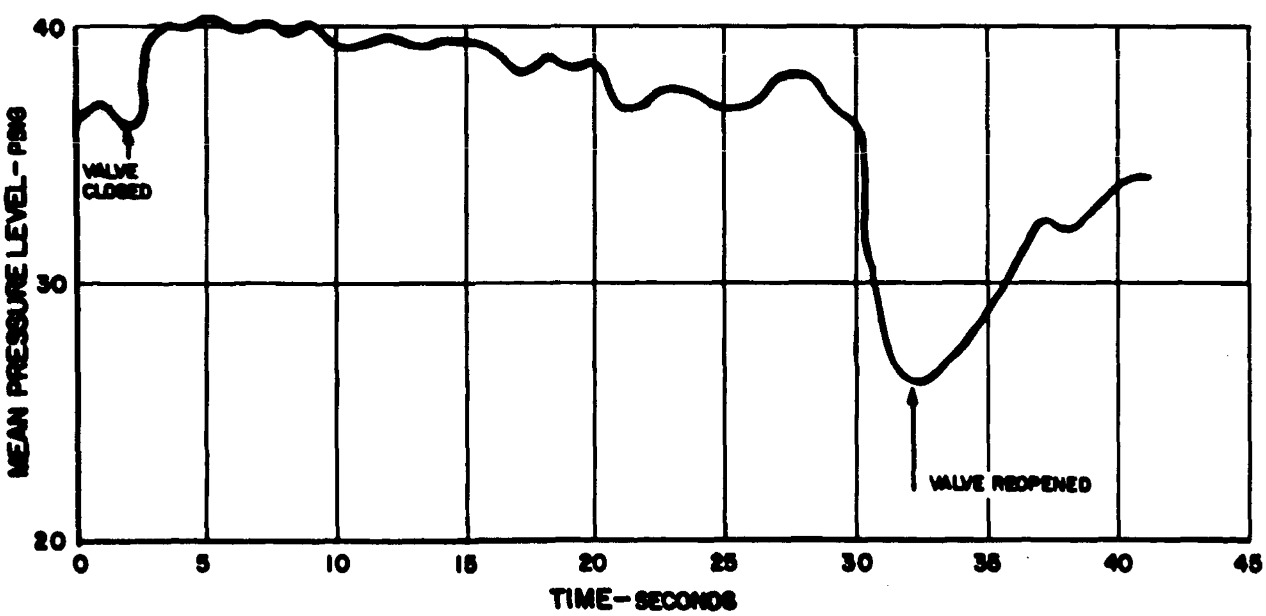


Figure 40 Mean Pressure Level vs Time Showing Effects of Shutting Off Coolant to Middle Cooling Sections: Test No. 9.11

Conditions:

1. Cooling Arrangement across Tubes
2. Orifices in Tube Exits
3. Tube Axes Horizontal, Tubes Stacked in Horizontal Plane
4. Condensing Steam Flow Rate per Tube prior to Shutoff = 0.021 lb/sec
5. Cooling Flow Rate per Tube prior to Shutoff = 0.81 lb/sec
6. Large Inlet Header

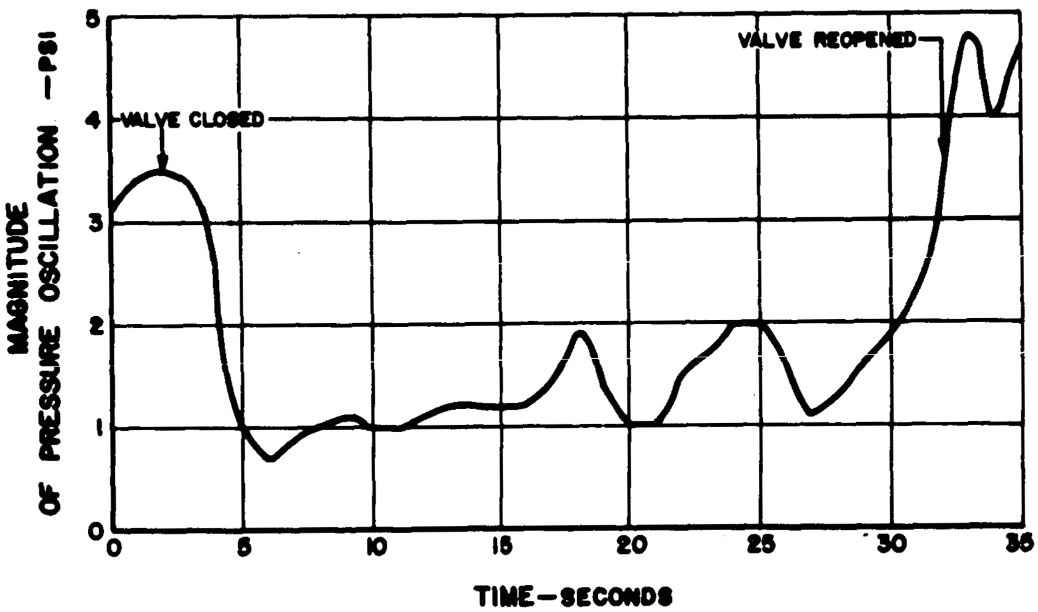
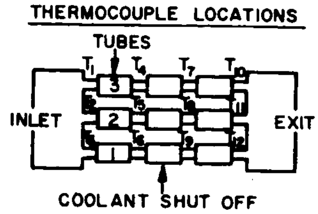


Figure 41 Magnitude of Pressure Oscillation at Exit Header vs Time Showing Effects of Shutting Off Coolant to Middle Cooling Sections. Test No. 9.11

Conditions:
1. Cooling Arrangement across Tubes
2. Orifices in Tube Exits
3. Tube Axes Horizontal, Tubes Stacked in Horizontal Plane
4. Condensing Steam Flow Rate per Tube prior to Shutoff = 0.021 lb/sec
5. Cooling Flow Rate per Tube prior to Shutoff = 0.81 lb/sec
6. Cooling Sections Shut Off - Middle
7. Large Inlet Header



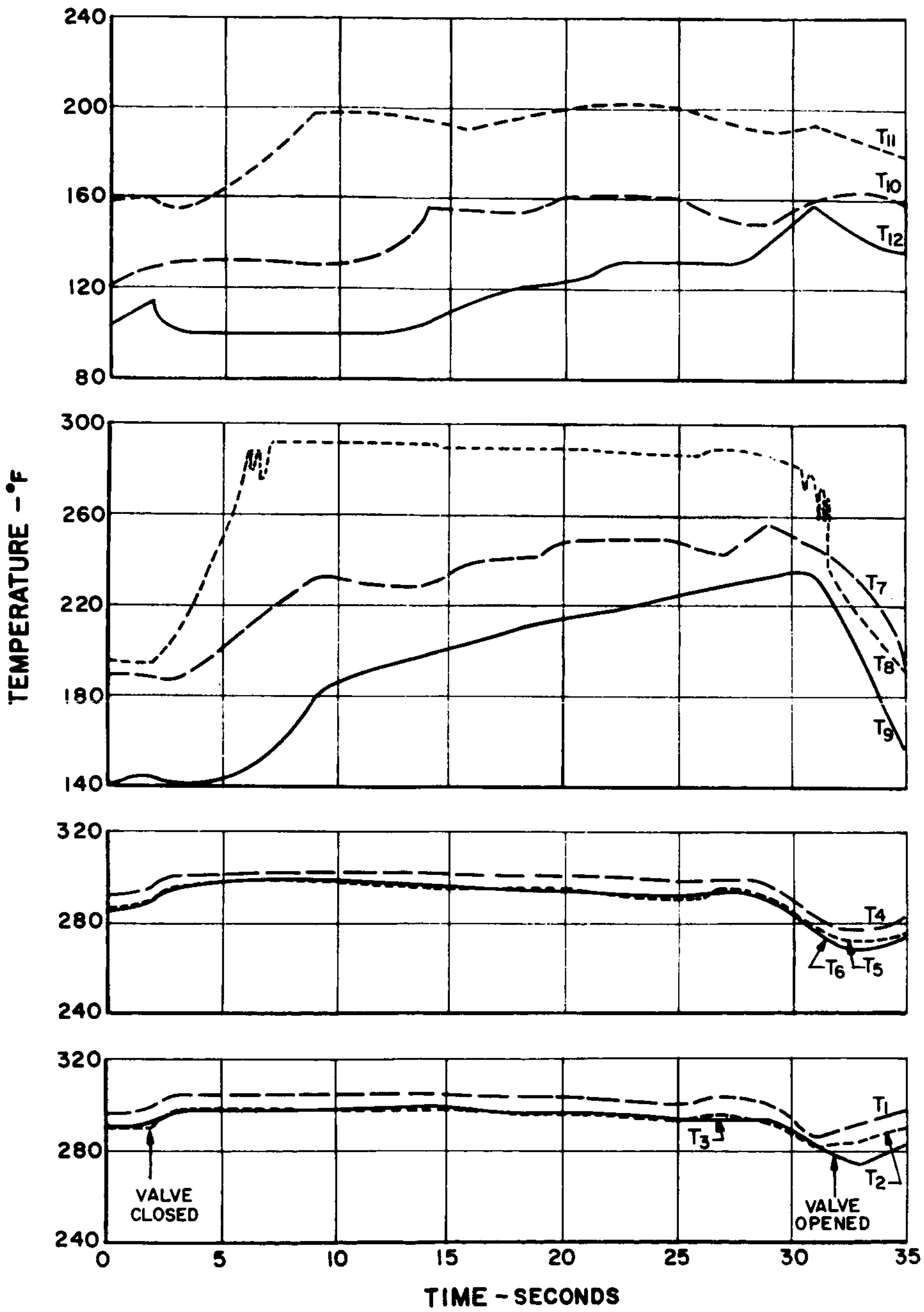


Figure 42 Condensing Fluid Mean Temperature at Various Locations vs Time. Test No. 9.11

Conditions:
1. Cooling Arrangement across Tubes
2. Orifices in Tube Exits
3. Tube Axes Horizontal, Tubes Stacked in Horizontal Plane
4. Condensing Steam Flow Rate per Tube prior to Shutoff = 0.021 lb/sec
5. Cooling Flow Rate per Tube prior to Shutoff = 0.81 lb/sec
6. Large Inlet Header

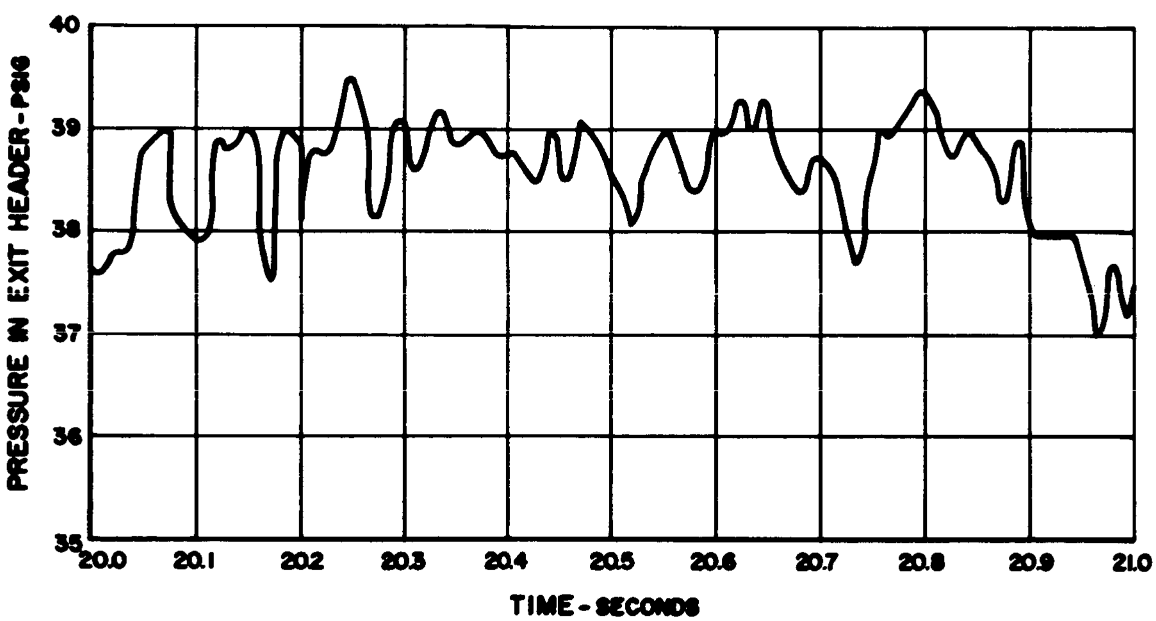


Figure 43 Typical Curve of Pressure in Exit Header vs Time during Period Coolant to Middle Cooling Sections is Shut Off. Test No. 9.11

Conditions:

1. Cooling Arrangement Parallel to Tubes
2. No Orifices
3. Tube Axes Horizontal, Tubes Stacked in Vertical Plane
4. Condensing Steam Flow Rate per Tube prior to Shutoff = 0.022 lb/sec
5. Cooling Flow Rate per Tube prior to Shutoff = 0.81 lb/sec
6. Large Inlet Header

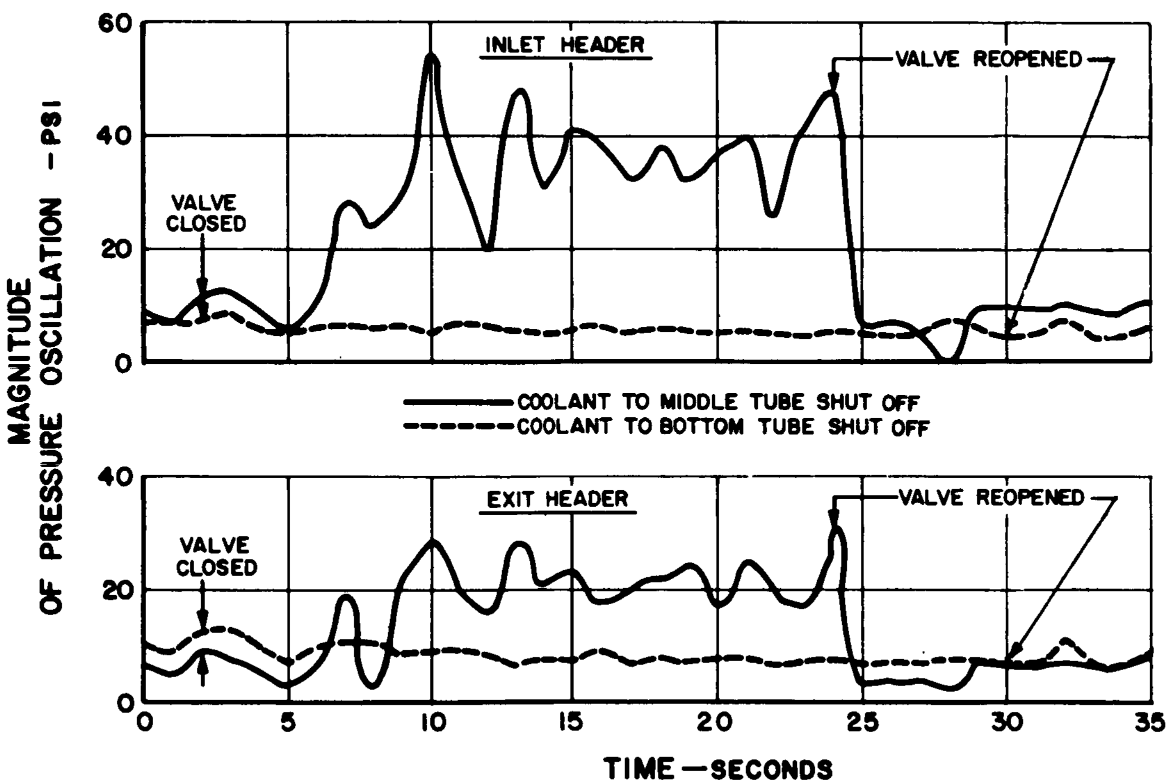


Figure 44 Magnitude of Pressure Oscillation vs Time Showing Effects of Shutting Off Coolant to Different Tubes. Tests Nos. 9.16 and 9.17

Conditions:

1. Cooling Arrangement Parallel to Tubes
2. No Orifices
3. Tube Axes Horizontal, Tubes Stacked in Vertical Plane
4. Condensing Steam Flow Rate per Tube prior to Shutoff = 0.022 lb/sec
5. Cooling Flow Rate per Tube prior to Shutoff = 0.81 lb/sec
6. Large Inlet Header

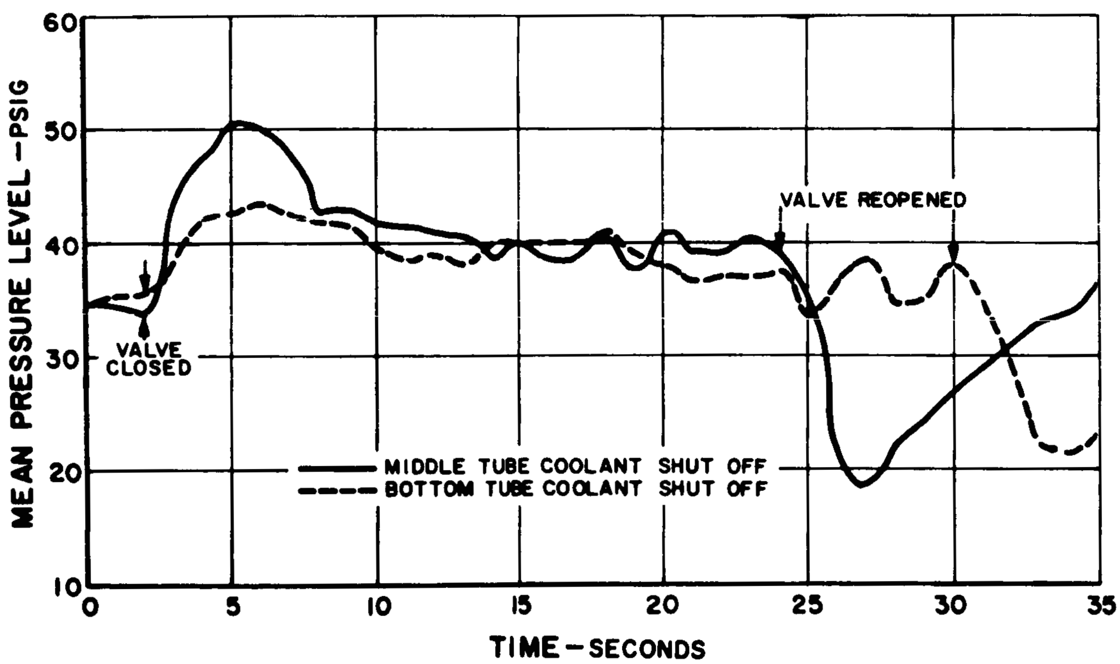


Figure 45 Mean Pressure Level vs Time Showing Effects of Shutting Off Coolant to Different Tubes. Tests Nos. 9.16 and 9.17

Conditions:

1. Cooling Arrangement Parallel to Tubes
2. No Orifices
3. Tube Axes Horizontal, Tubes Stacked in Vertical Plane
4. Condensing Steam Flow Rate per Tube prior to Shutoff = 0.022 lb/sec
5. Cooling Flow Rate per Tube prior to Shutoff = 0.81 lb/sec
6. Large Inlet Header

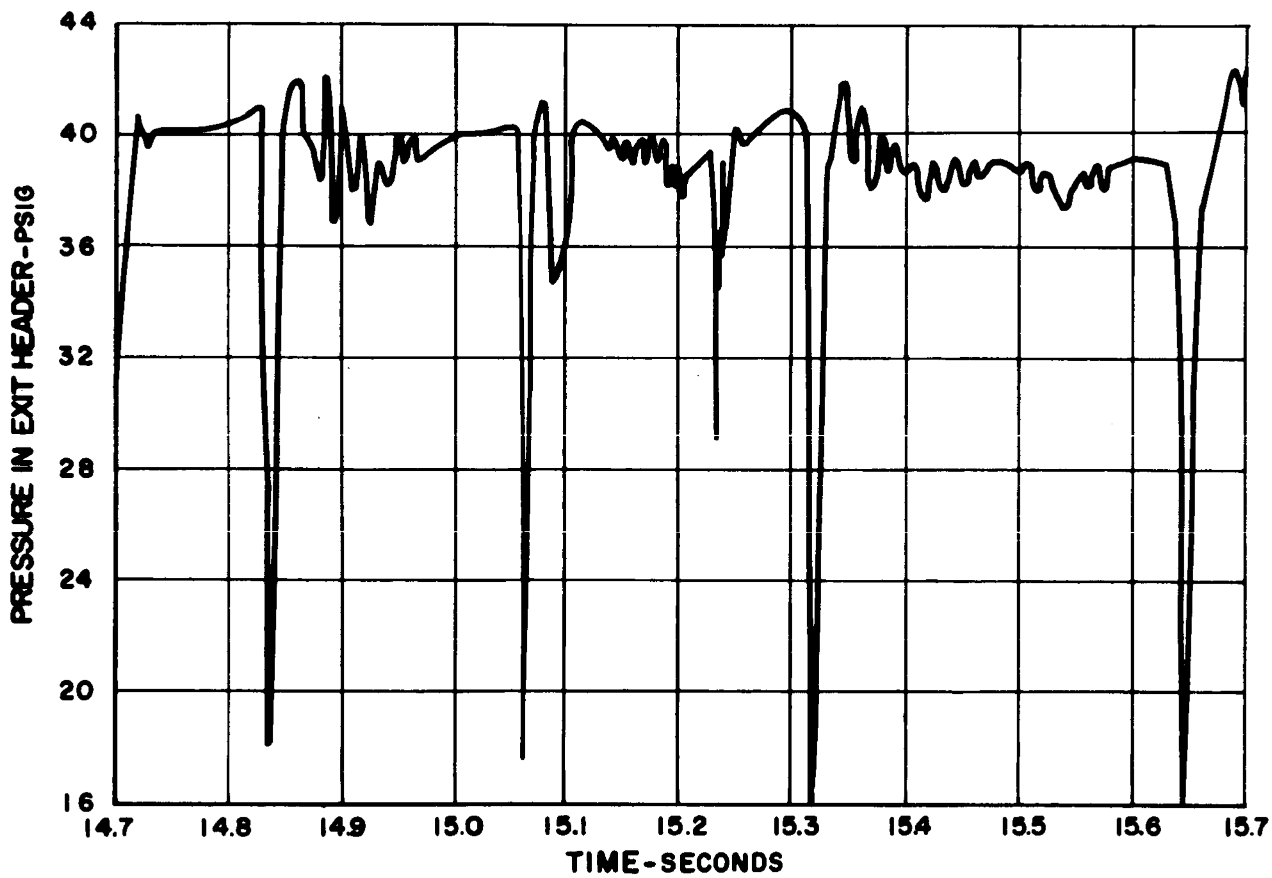


Figure 46 Typical Curve of Pressure in Exit Header vs Time during Period Coolant to Middle Tube is Shut Off. Test No. 9.16

Conditions:

1. Cooling Arrangement Parallel to Tubes
2. No Orifices
3. Tube Axes Horizontal, Tubes Stacked in Vertical Plane
4. Condensing Steam Flow Rate per Tube prior to Shutoff = 0.022 lb/sec
5. Cooling Flow Rate per Tube prior to Shutoff = 0.81 lb/sec
6. Coolant to Middle Tube Shut Off
7. Large Inlet Header

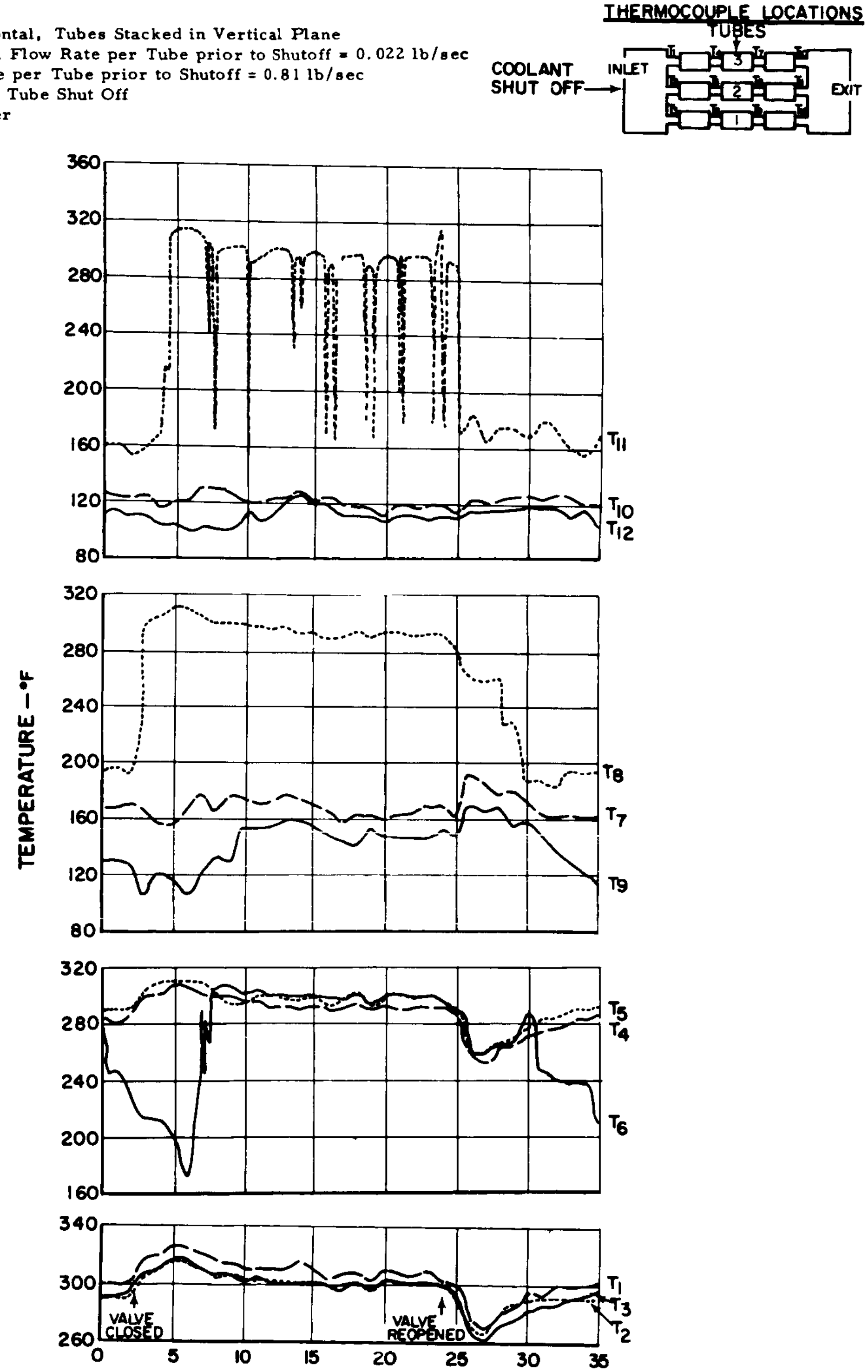


Figure 47 Condensing Fluid Mean Temperature at Various Locations vs Time. Test No. 9.16

Conditions:
1. Cooling Arrangement Parallel to Tubes
2. No Orifices
3. Tube Axes Horizontal, Tubes Stacked in Vertical Plane
4. Condensing Steam Flow Rate per Tube prior to Shutoff = 0.022 lb/sec
5. Cooling Flow Rate per Tube prior to Shutoff = 0.81 lb/sec
6. Coolant to Bottom Tube Shut Off
7. Large Inlet Header

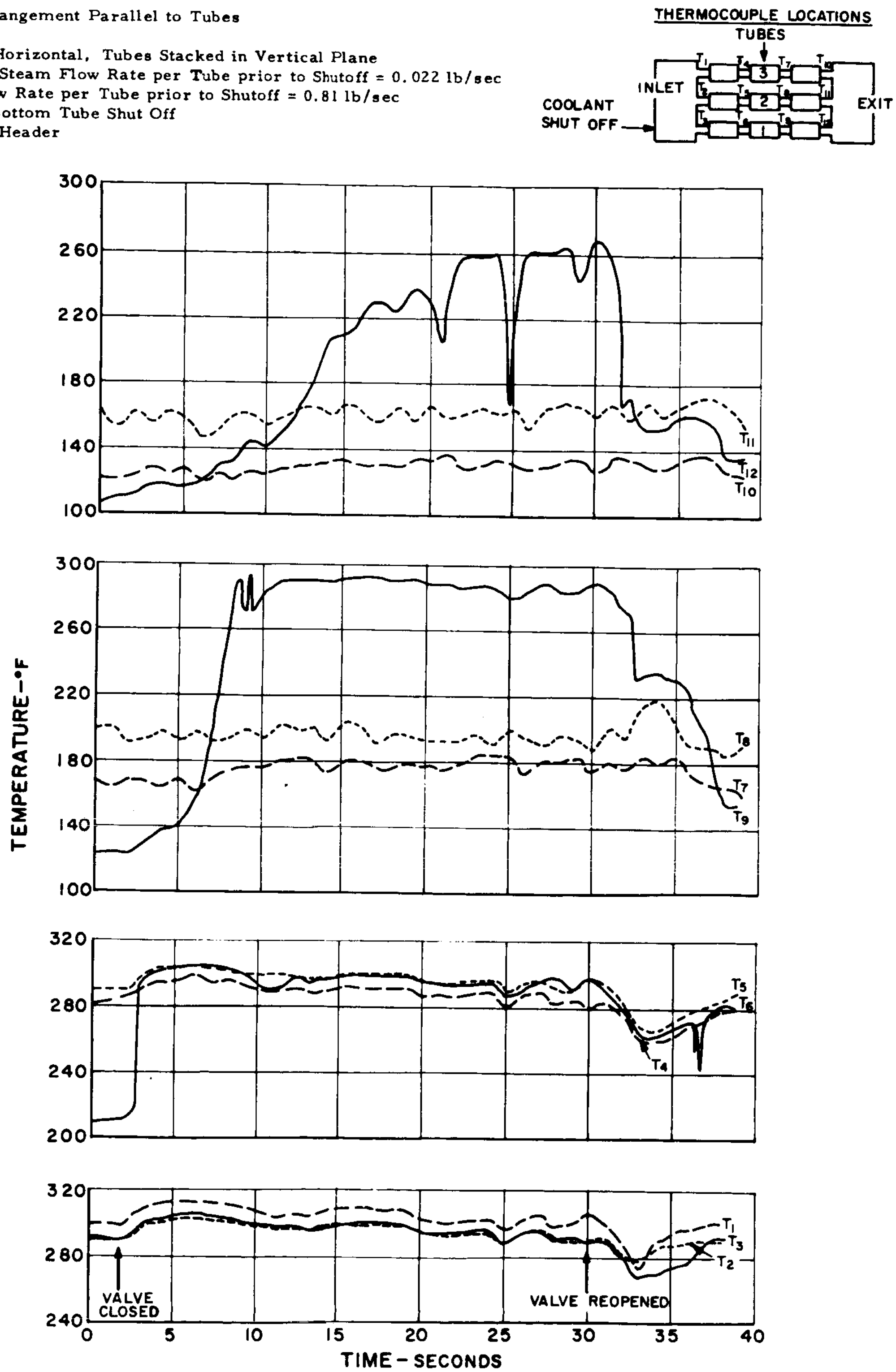


Figure 48 Condensing Fluid Mean Temperature of Various Locations vs Time. Test No. 9.17

Conditions:

1. Cooling Arrangement Parallel to Tubes
2. Orifices in Tube Exits
3. Tube Axes Horizontal, Tubes Stacked in Vertical Plane
4. Condensing Steam Flow Rate per Tube prior to Shutoff = 0.022 lb/sec
5. Cooling Flow Rate per Tube prior to Shutoff = 0.81 lb/sec
6. Large Inlet Header

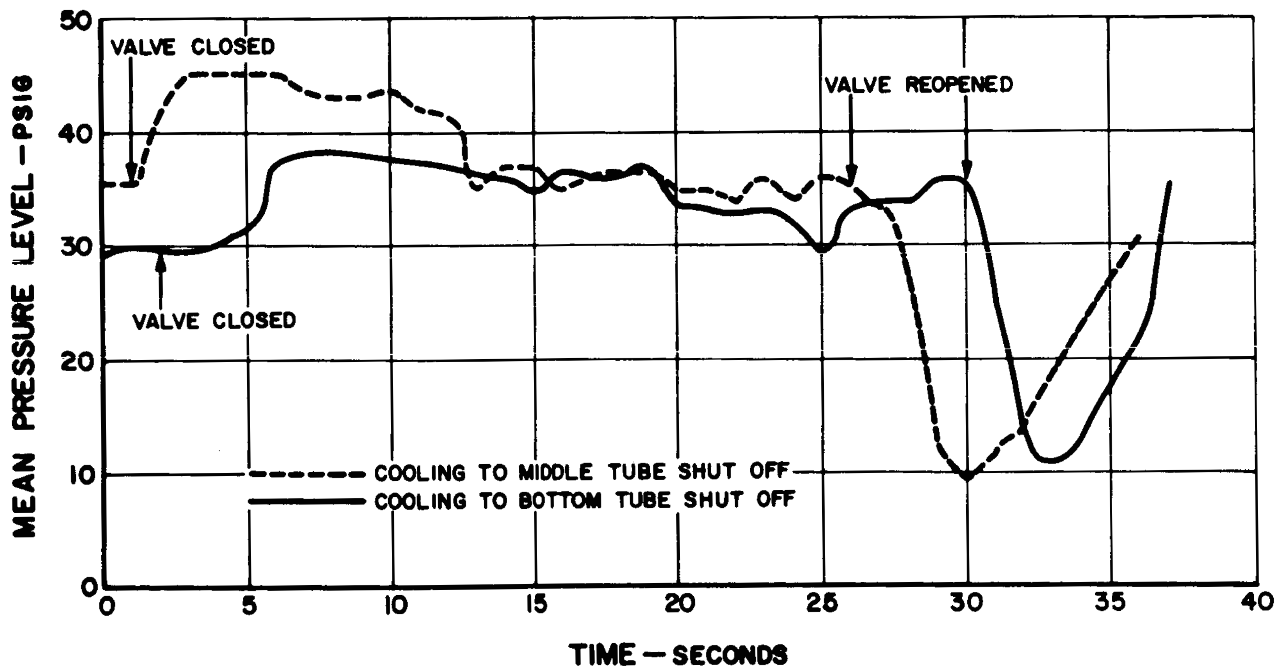


Figure 49 Mean Pressure Level vs Time Showing Effects of Shutting Off Coolant to Different Tubes. Tests Nos. 9.19 and 9.20

Conditions:
1. Cooling Arrangement Parallel to Tubes
2. Orifices in Tube Exits
3. Tubes Axes Horizontal, Tubes Stacked in Vertical Plane
4. Condensing Steam Flow Rate per Tube prior to Shutoff = 0.022 lb/sec
5. Cooling Flow Rate per Tube prior to Shutoff = 0.81 lb/sec
6. Large Inlet Header

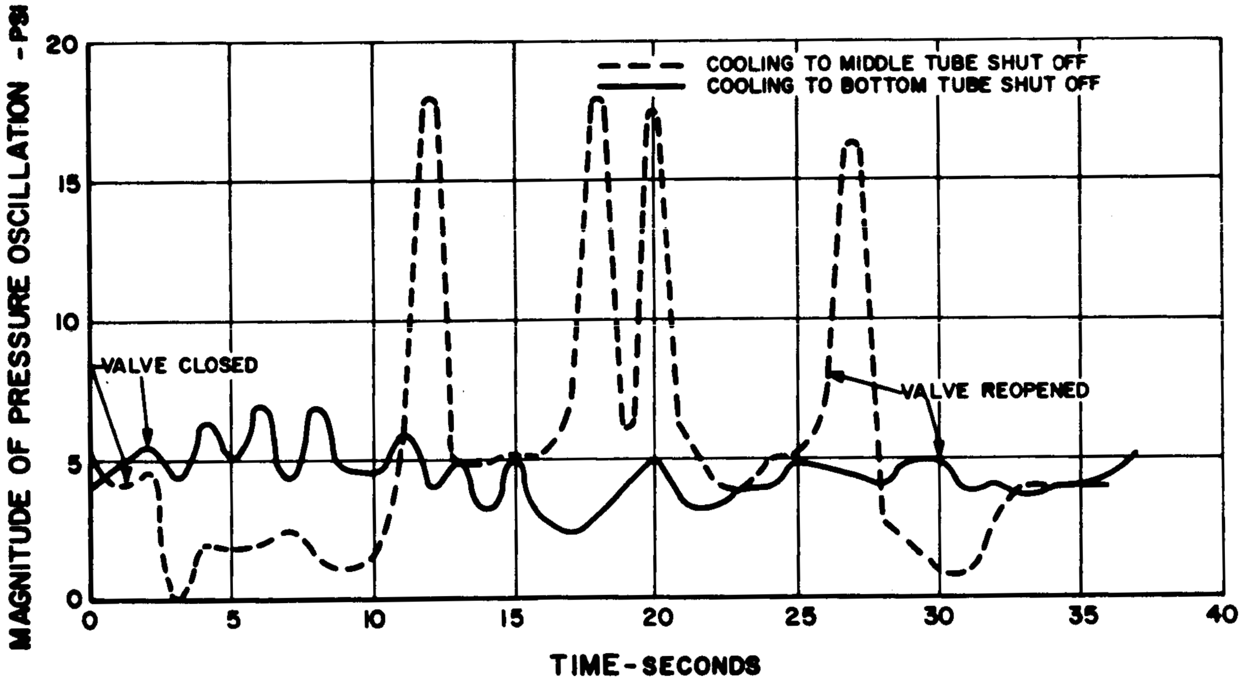
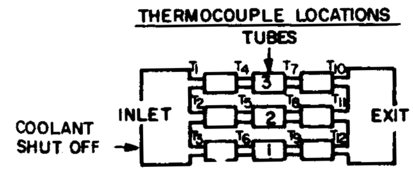


Figure 50 Magnitude of Pressure Oscillation at Exit Header vs Time Showing Effects of Shutting Off Coolant to Different Tubes. Tests Nos. 9.19 and 9.20

Conditions:
1. Cooling Arrangement Parallel to Tubes
2. Orifices in Tube Exits
3. Tube Axes Horizontal, Tubes Stacked in Vertical Plane
4. Condensing Steam Flow Rate per Tube prior to Shutoff = 0.022 lb/sec
5. Cooling Flow Rate per Tube prior to Shutoff = 0.81 lb/sec
6. Coolant to Bottom Tube Shut Off
7. Large Inlet Header



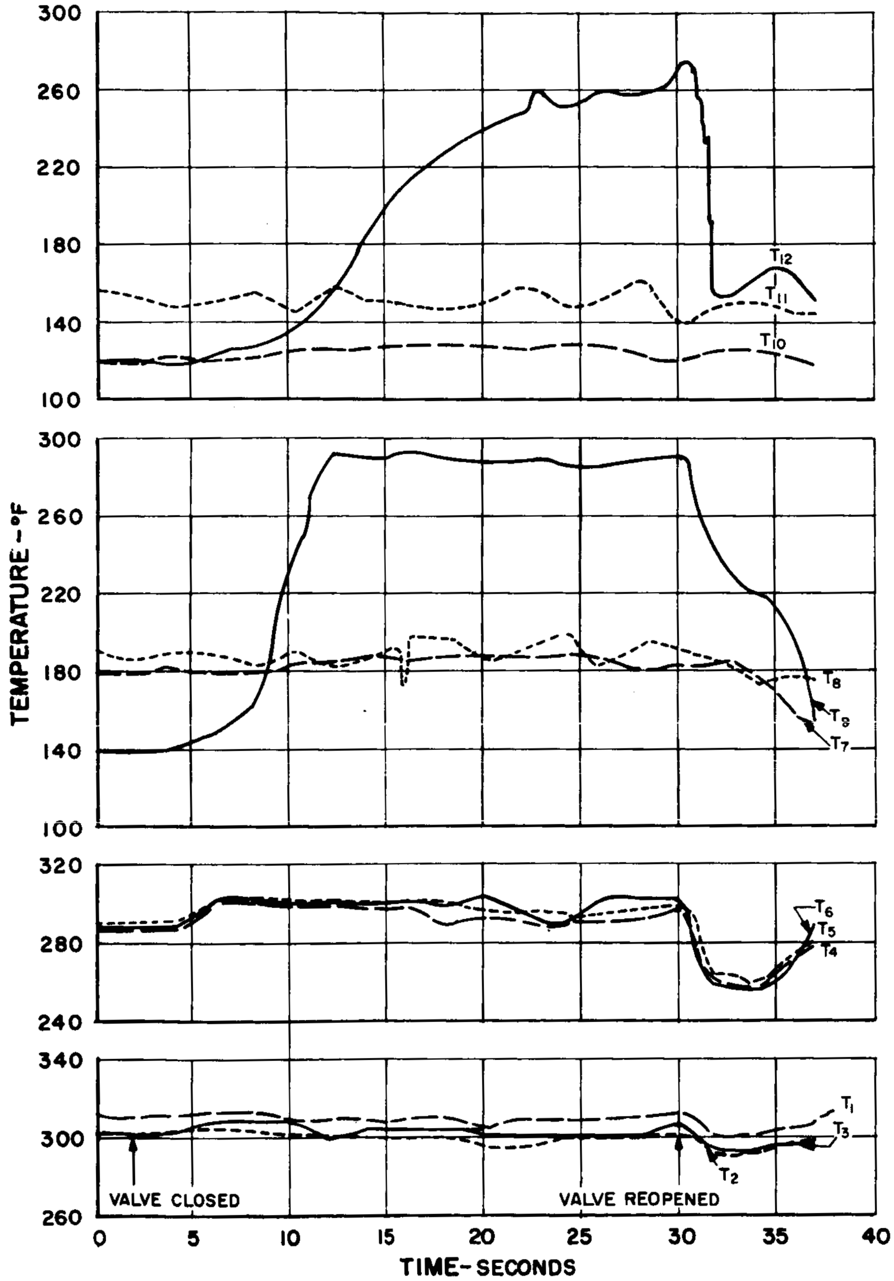


Figure 51 Condensing Fluid Mean Temperature at Various Locations vs Time. Test No. 9.20

Conditions:
1. Cooling Arrangement Parallel to Tubes
2. Orifices in Tube Exits
3. Tube Axes Horizontal, Tubes Stacked in Vertical Plane
4. Condensing Steam Flow Rate per Tube prior to Shutoff = 0.022 lb/sec
5. Cooling Flow Rate per Tube prior to Shutoff = 0.81 lb/sec
6. Large Inlet Header

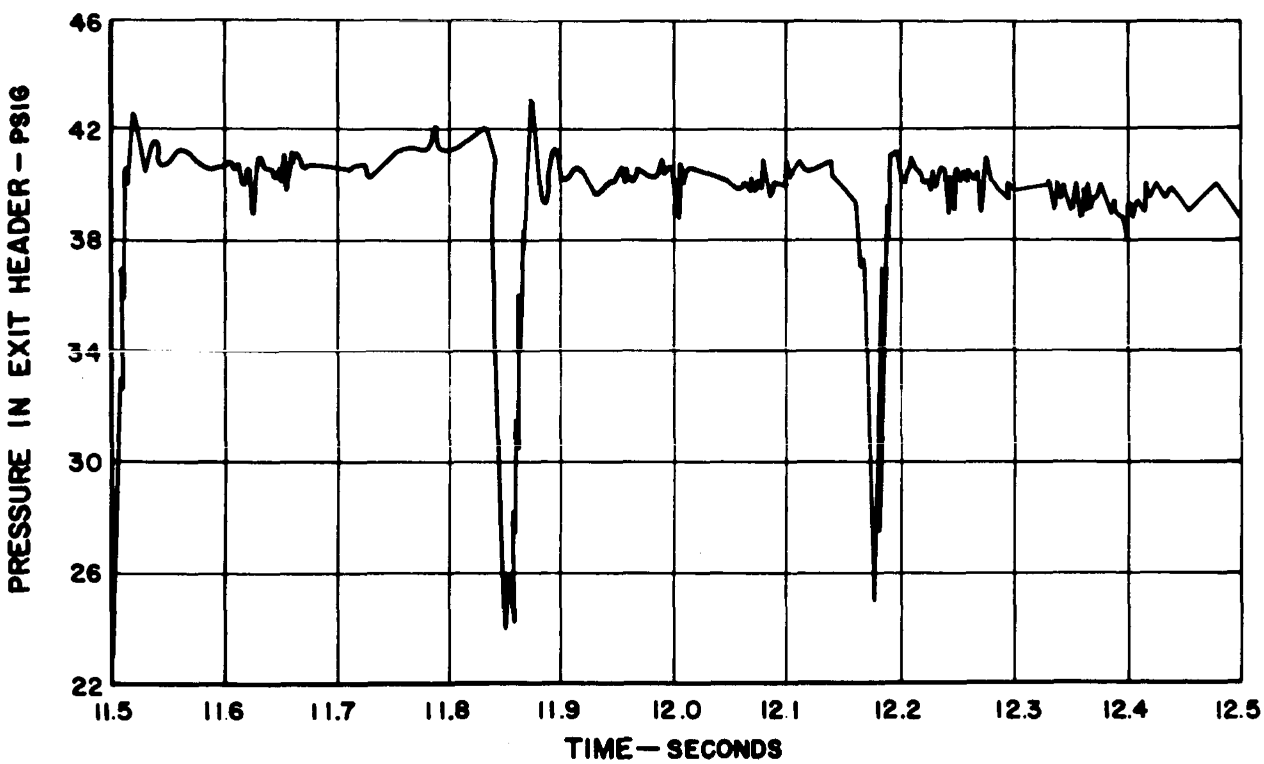
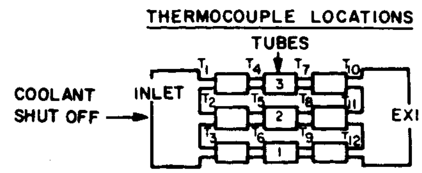


Figure 52 Typical Curve of Pressure in Exit Header vs Time during Period Coolant to Middle Tube is Shut Off. Test No. 9.19

Conditions:

1. Cooling Arrangement Parallel to Tubes
2. Orifices in Tube Exits
3. Tube Axes Horizontal, Tubes Stacked in Vertical Plane
4. Condensing Steam Flow Rate per Tube prior to Shutoff = 0.022 lb/sec
5. Cooling Flow Rate per Tube prior to Shutoff = 0.81 lb/sec
6. Coolant to Middle Tube Shut Off
7. Large Inlet Header



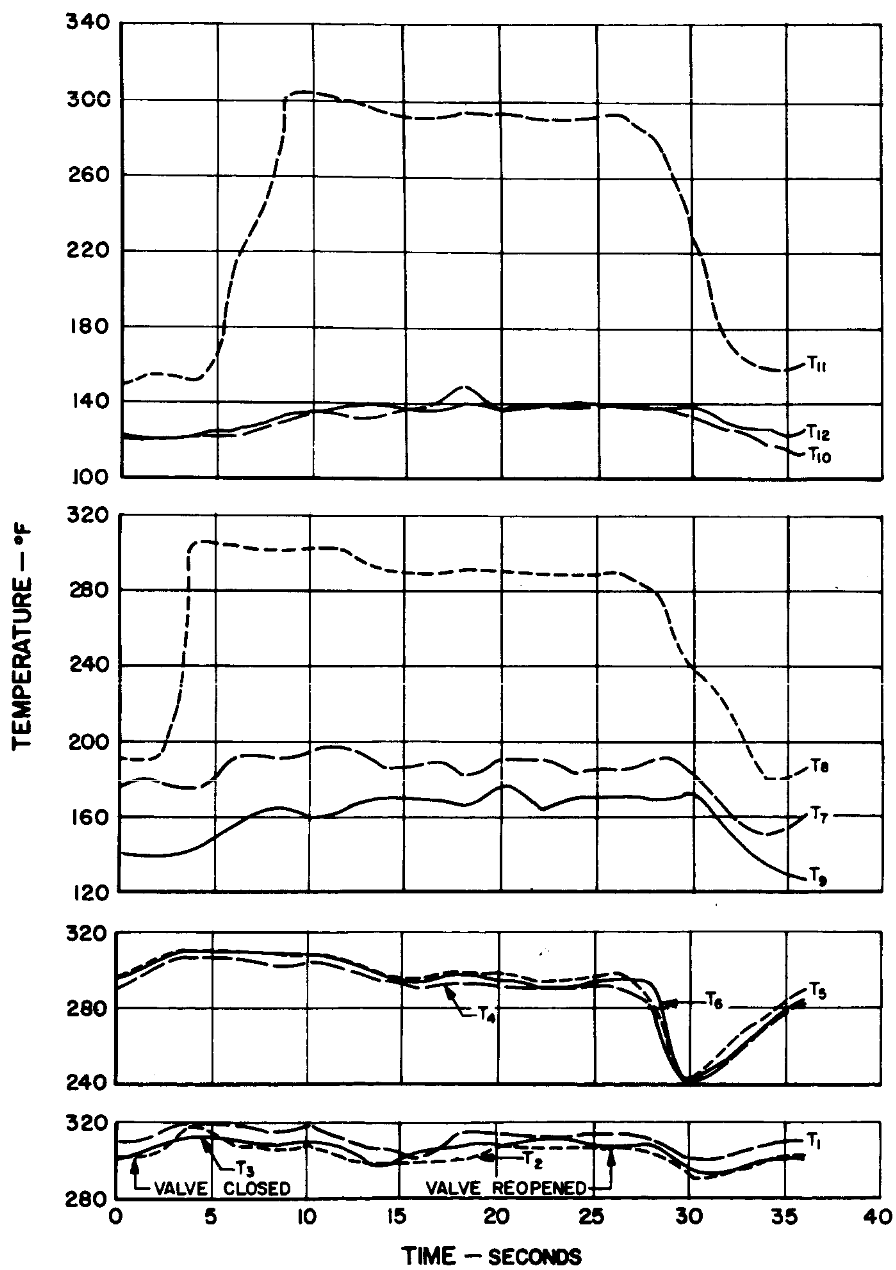


Figure 53 Condensing Fluid Mean Temperature at Various Locations vs Time. Test No. 9.19

Conditions:
1. Cooling Arrangement Parallel to Tubes
2. Orifices in Tube Exits
3. Tube Axes Vertical
4. Condensing Steam Flow Rate per Tube prior to Shutoff = 0.018 lb/sec
5. Cooling Flow Rate per Tube prior to Shutoff = 0.81 lb/sec
6. Coolant to Middle Tube Shut Off
7. Large Inlet Header

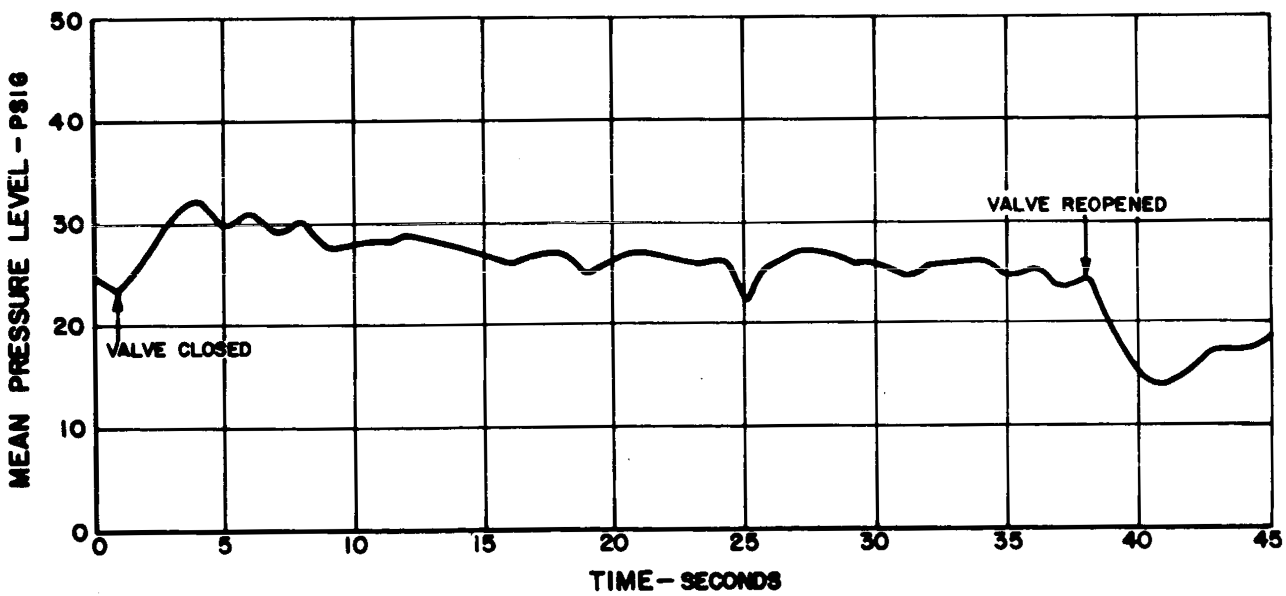


Figure 54 Mean Pressure Level vs Time Showing Effects of Shutting Off Coolant to Middle Tube. Test No. 9-23

Conditions:
1. Cooling Arrangement Parallel to Tubes
2. Orifices in Tube Exits
3. Tube Axes Vertical
4. Condensing Steam Flow Rate per Tube prior to Shutoff = 0.018 lb/sec
5. Cooling Flow Rate per Tube prior to Shutoff = 0.81 lb/sec
6. Large Inlet Header

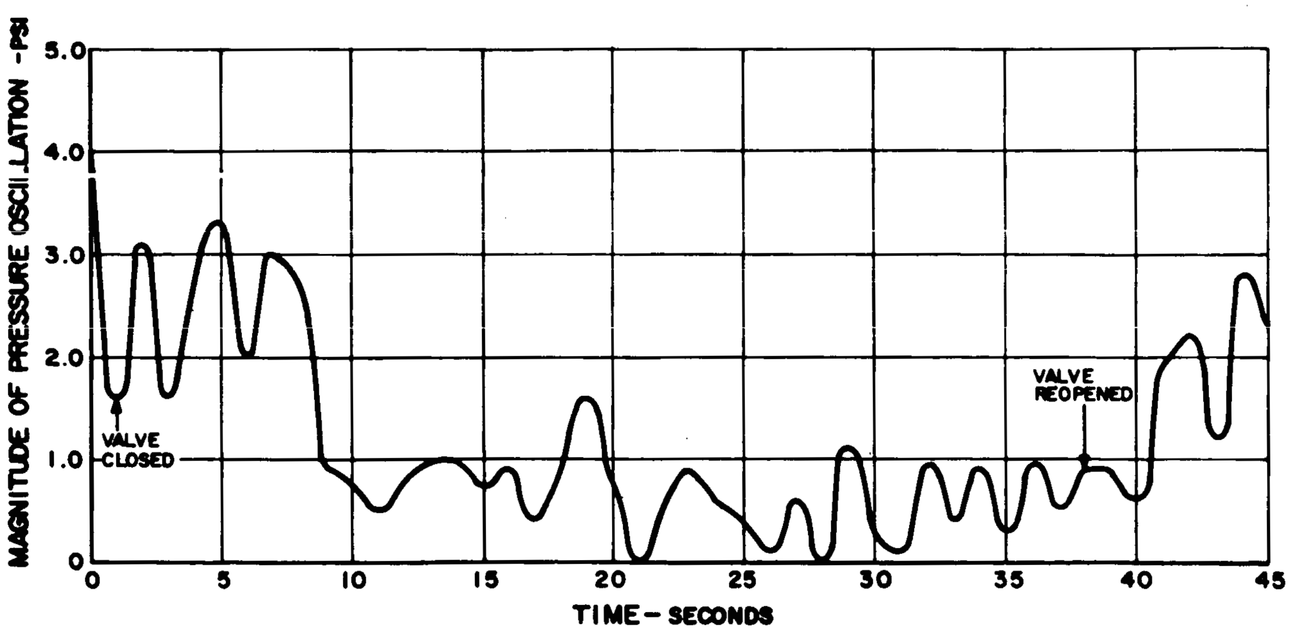


Figure 55 Magnitude of Pressure Oscillation at Exit Header vs Time Showing Effects of Shutting Off Coolant to Middle Tube. Test No. 9.23

Conditions:
1. Cooling Arrangement Parallel to Tubes
2. Orifices in Tube Exits
3. Tube Axes Vertical
4. Condensing Steam Flow Rate per Tube prior to Shutoff = 0.018 lb/sec
5. Cooling Flow Rate per Tube prior to Shutoff = 0.81 lb/sec
6. Large Inlet Header

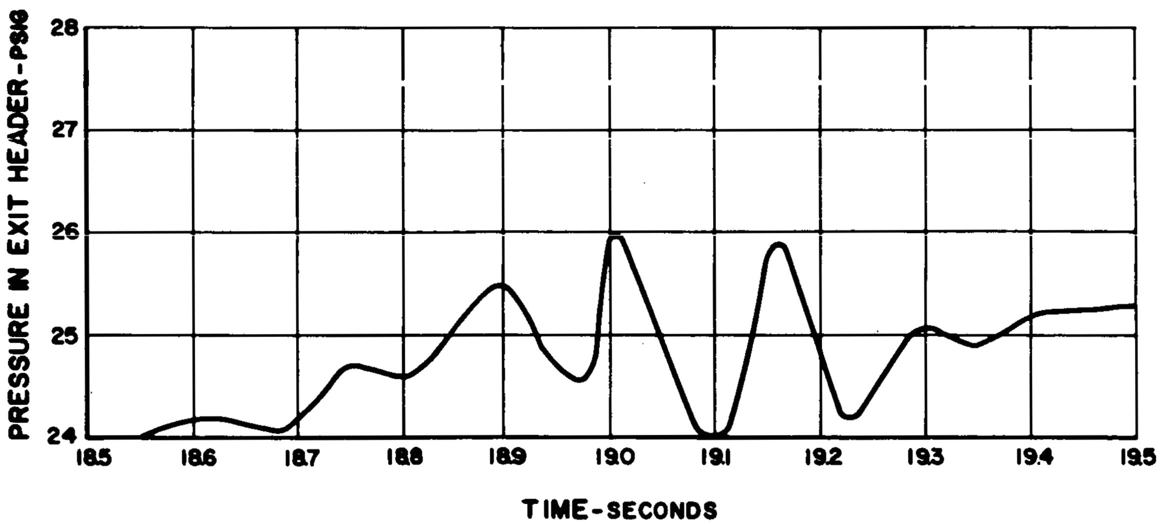
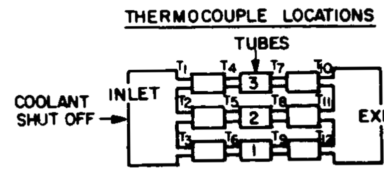


Figure 56 Typical Curve of Pressure in Exit Header vs Time during Period Coolant to Middle Tube is Shut Off. Test No. 9.23

Conditions
1. Cooling Arrangement Parallel to Tubes
2. Orifices in Tube Exits
3. Tube Axes Vertical
4. Condensing Steam Flow Rate per Tube prior to Shutoff = 0.018 lb/sec
5. Cooling Flow Rate per Tube prior to Shutoff = 0.81 lb/sec
6. Coolant to Middle Tube Shut Off
7. Large Inlet Header



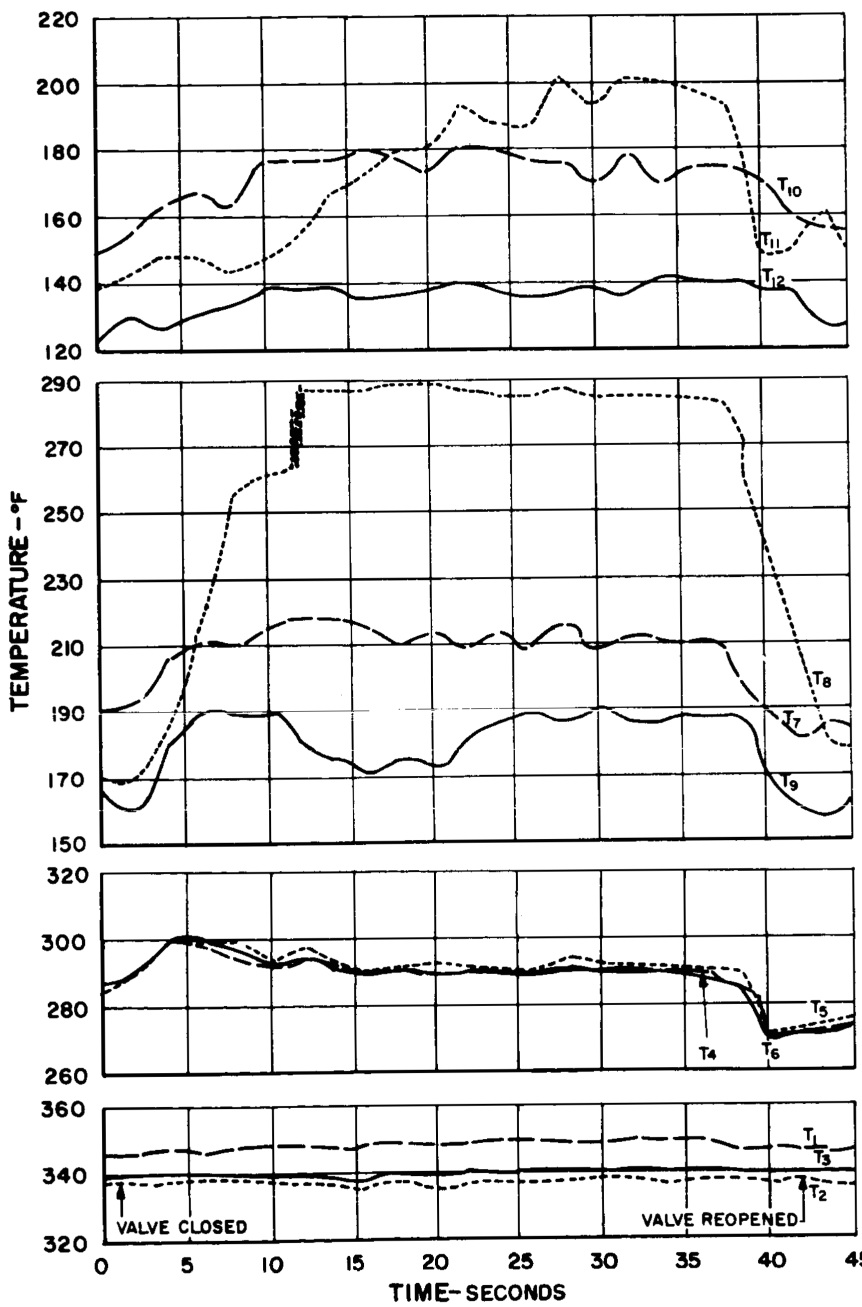


Figure 57 Condensing Fluid Mean Temperature at Various Locations vs Time. Test No. 9.23

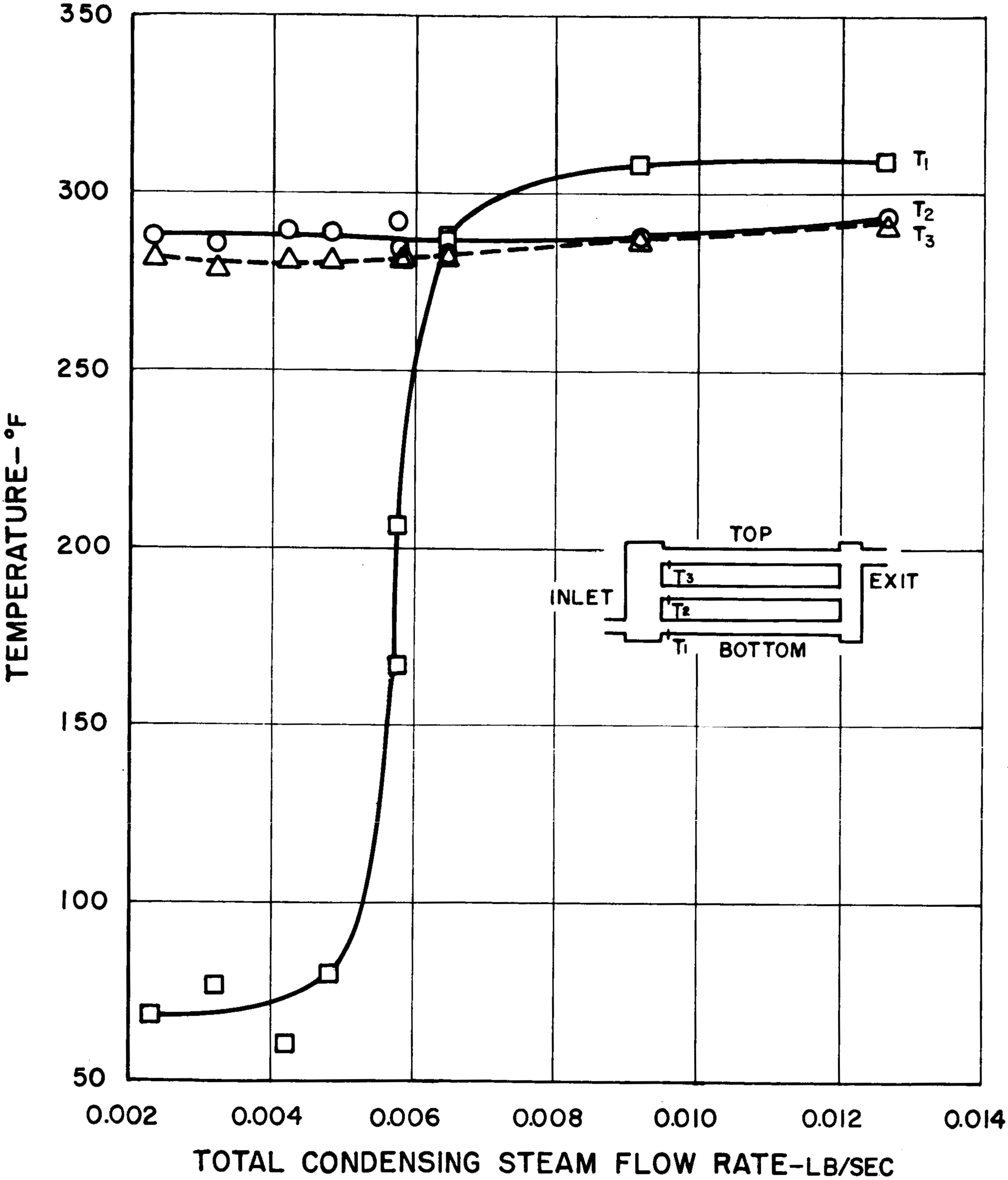


Figure 58   Temperatures at Tube Inlets vs Condensing Steam Flow Rate for Simulated Condensing-Radiator Configuration

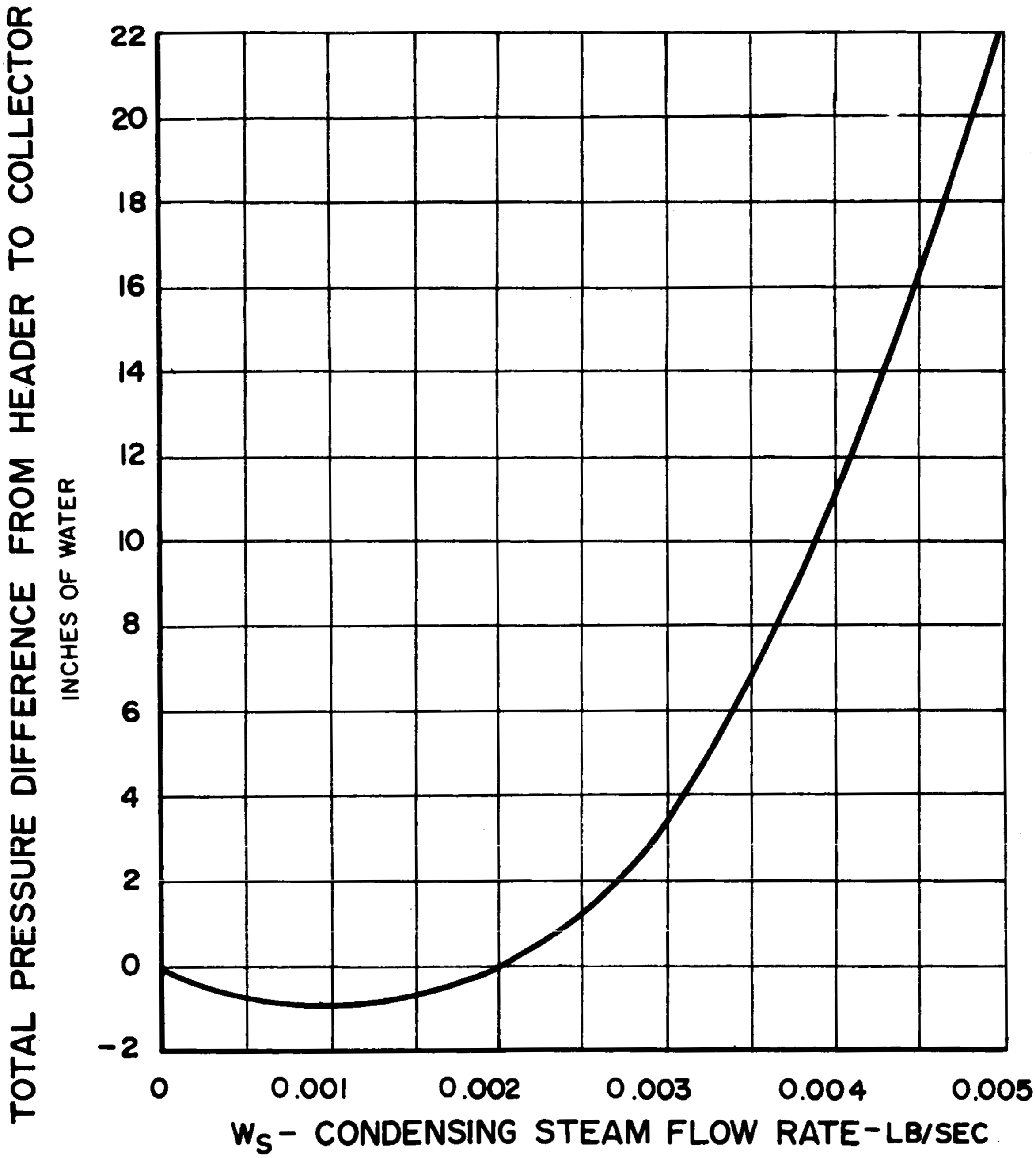


Figure 59 Total Pressure Difference from Header to Collector vs Flow Rate for Condensing Steam
Conditions:
1. Static pressure at inlet = 50 psia
2. Coolant flow rate per branch = 0.82 lb/sec
3. Subcooled water at exit
4. Steam at inlet near saturation point
5. Tube inside diameter = 0.180 inch

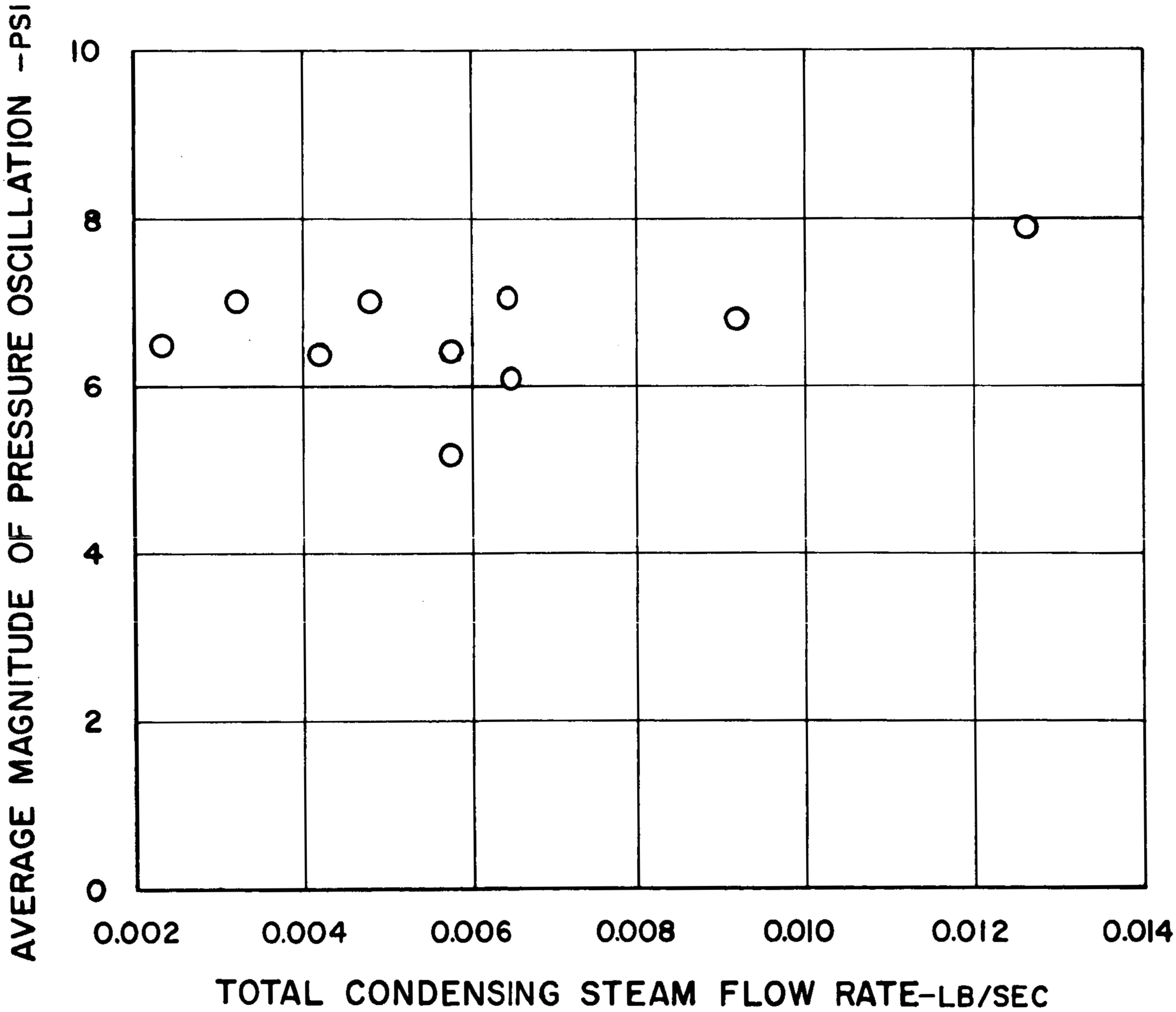


Figure 60 Average Magnitude of Pressure Oscillation in Exit Manifold vs Condensing Steam Flow Rate for Simulated Condensing Radiator Configuration